# Project Report
## First Phase: 1999 - 2001

# Improving crop-livestock productivity through efficient nutrient management in mixed farming systems of semi-arid West Africa
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# Gestion efficiente des éléments minéraux dans les systèmes culture-élevage en zone semi-aride d'Afrique de l'Ouest

# NUTMAN/GEMS

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**&**

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Executed by

The International Livestock Research Institute (ILRI, lead institute), l’Institut d’Economie Rurale (IER, Mali), l’Institut de l’Environnement et des Recherches Agricoles (INERA, Burkina Faso), l’Institut National de Recherches Agronomiques du Niger (INRAN, Niger), l’Institut Sénégalais de Recherche Agricole (ISRA, Senegal), the International Crops Research Institute for the Semi-arid Tropics (ICRISAT) and the International Fertilizer Development Center (IFDC).

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## I. Goal of project

The goal of the NUTMAN- GEMS project is to contribute to poverty alleviation and improvement of food security in semi-arid West Africa through increased agricultural production. The **overall objective** is to increase the productivity of crop-livestock farming systems in semi-arid West Africa through better soil nutrient management. In the first phase of the project, from 1999 to 2001, the **specific objectives** were:

a) To assess ex-ante the potential impact and acceptability of technological alternatives on nutrient management.
b) To improve the efficacy of livestock mediated nutrient transfers within village territories through better land use and institutional arrangements
c) To promote adoption of nutrient management interventions through the identification of appropriate economic incentives and policy options
d) To improve soil fertility, and hence food crop and fodder production through strategic and efficient use of crop stalks, animal manure, local rock phosphates, chemical fertilizers and forage legumes.
e) To increase meat and milk production and livestock contribution to efficient soil-plant nutrient cycling through better utilization of available feed resources.

## II. Introduction

Semi-arid West Africa is one of the regions of the world where rural poverty and food insecurity are of highest concern. The main biophysical constraint to increased production of both crops and livestock in the region is the inadequate availability of protein, metabolisable energy and phosphorus for livestock production and nitrogen, phosphorus and organic matter for crop production. Growth in human and livestock populations has led to an expansion of cultivated land and shortened fallow periods. This in turn, has promoted land degradation and decreased soil fertility. At the same time, low rural incomes, inappropriate policies and infrastructural constraints have prevented the widespread use of inputs such as inorganic fertilizers and feed supplements. In response to this trend, farming systems have evolved towards more integrated forms of crop and livestock production in order to harness the complementary benefits inherent in mixed crop-livestock systems.

Although rural production systems across the Sahel share many common traits including similar climate, crops, livestock species and social institutions, local particularities do exist which are reflected in the choice of 9 benchmark sites of this project (Table 1). The list of benchmark site has been revised along with the project progresses (1999, 2000 and 2001 progress reports): some of the sites initially included were dropped off and other grouped into more coherent sites. The agro-ecosystems and farming systems dropped in the course of the first phase of the project include the irrigated rice based system in semi-arid Mali, centered on the 'Office du Niger' rice scheme, in Niono, Mali; the southern part of the groundnut belt centered on Kaolack, Senegal; the irrigated peri-urban systems of the Niayes, east of Dakar, Senegal. A systematic summary definition of each of the nine sites is given below:

1. Subsistence crop-livestock farming in northern Sahel (300-450 mm): millet-cowpea + sorghum in low land, cattle-sheep-goat husbandry, sheep fattening with dairy cows and goats production. Site Dori, village: Lelly, Katchary research station. Burkina Faso
2. Subsistence crop-livestock farming in soudano-sahelian zone (600-900 mm): sorghum-cowpea, millet-cowpea, groundnut, rice in low lands, small stock husbandry,

poultry, and draft oxen. Site Saria, village: Namanéguéma, Saria research station. Burkina Faso

3. Subsistence and commercial mixed crop-livestock peri-urban systems in south Sahel (500-600 mm): sorghum-cowpea, millet-cowpea, groundnut, dah, fonio, tomatoes...cattle-sheep and goats husbandry, draft oxen, sheep and cattle fattening, dairy cows, Site: Ségou, villages:Bakawèré, Kondogola, Dakala, Mpénébougou, Nyatia, Zirakoro, Sonogola, Cinzana research station. Mali
4. Subsistence and commercial mixed crop-livestock system in southern Sahel (600-800 mm): sorgho-cowpea, millet-cowpea, groundnut, sesame, cotton, dah, water melon... cattle-sheep-goat husbandry, draft oxen, sheep and cattle fattening. Site San, villages: Cinzara, Yorobougou. Bobowere, toura-marka, Mali
5. Subsistence crop-livestock system in the Sahel (300-450 mm): millet-cowpea, low-land sorghum (+ locally: sorrel, sesame, peper… cattle-sheep and goats husbandry. Sites: Diffa, Tahoua, villages: Ala Damaram, tam Nadara, Badiguichiri. Niger
6. Subsistence crop-livestock systems in the southern Sahel (450-600 mm): millet - cowpea-sorrel, sesame, groundnut... cattle-sheep and goats husbandry, sheep fattening, Sites Dantiandou, Sadoré, villages: Banizoumbou, TigoTégui, Katanga, Kodey, Sadoré, Gobéri, Karabédji, Sadoré research station. Niger
7. Subsistence and commercial crop-livestock systems in soudano-sahelian zone (600-800 mm): sorghum-cowpea, millet-cowpea, groundnut, maize, cotton, sorrel, pumpkin…ttle-sheep and goats husbandry, draft oxen, cattle and sheep fattening. Sites: Gaya, Maradi villages: Bengou, Guidam Tanio Hardo Alto, Doguerawa, research station: Bengou, Aguié, Niger
9. Subsistence and commercial crop-livestock systems of irrigated lands in the Niger River valley of peri-urban Niamey (450-600 mm): irrigated rice, sorghum, maize, vegetables, fruit trees... Draft oxen, sheep fattening, dairy cows, Sites Kollo, Tillabéry, villages: Kirkissoye, Say Ndouga, Youri Say, Niamé, Kollo research. Niger
10. Subsistence and commercial crop-livestock systems in the Sahel (350-550 mm): millet-groundnut, cowpea… cattle-sheep and goats husbandry, draft oxen and horses, dairy cows and sheep fattening. Site: Diourbel, villages: Kane-kane, Keur Ségue, Loumène Bengou, Mbari Ndondol. Bambey research station. Sénégal.

The benchmark sites lie within a range of 200 – 900 mm annual rainfall and are representative of many other locations in the Sahel. Although soils in the Sahel are generally sandy and poor in organic matter content, soils in the benchmark sites differ in their overall fertility status, reflecting agricultural potential and past and present management options. Benchmark sites in San, southern Mali, Dori in northern Burkina Faso and Maradi in south-central Niger have more fertile tropical brown soils or alluvial soils than the other benchmark sites dominated by leached ferrugineous soils. Benchmark sites also differ in overall population density, level of poverty, market access and social institutions.

**Table 1**. General characteristics of the benchmark sites used in project in each of the four participating countries*.

| Country | Benchmark site | Research station | Villages of intervention | Rainfall (mm/yr) | Main crops | Agriculture intensification |
|---|---|---|---|---|---|---|
| Burkina Faso | Dori | Katchari | Lelly | 300-450 | rainfed millet-sorghum | low |
| | Saria, | Saria | Namaneguema | 600-900 | rainfed sorghum-millet; groundnut-cowpea | medium |
| Mali | Ségou, | Cinzana | Bakawere Kondogola Dakala Sanogola M'pénenbougou Nyantia Zirakoro | 450-700 | rainfed sorghum-millet; groundnut-cowpea | low |
| | San, | Cinzana | Cinzara, Yorobougou Toura Marka Bobowéré | 600-800 | rainfed, sorghum-millet; groundnut-cowpea | medium |
| Niger | Diffa-Tahoua, | - | Ala Damaram Tam; Nadara I Nadara II | 300-450 | rainfed , millet cowpea, sorghum | low |
| | Tillabéry | Sadoré Kollo | Banizoumbou, Tigotegui, Katanga, Kodey Sadoré | 450-600 | rainfed, millet-cowpea | low |
| | Gaya Maradi | Bengou Aguié | Guidam Tanio, Hardo Alto, Doguerawa Goberi Karabédji Bengou | 600-800 | rainfed sorghum-millet groundnut cowpea | medium |
| | Kollo | Kollo | Youri Say Niamè Ndounga Kirkissoye Sidi Koira | 450-600 | Irrigated, rice, sorghum, vegetables | high |
| Senegal | Diourbel, | Bambey | Kane-Kane, Keur Sègue Loumène Mbari Ndondol | 350-550 | rainfed, millet-groundnut | low |

* Sites and villages where socio-economic surveys were conducted are shaded in the table.

In 1999 and 2000, surveys were conducted to characterize the farming systems at each benchmark site. Farm households at the benchmark sites were classified into different recommendation domains based on endowments of land, livestock (cattle, sheep and goats) and family labor. From the diagnostic and through participatory discussions involving the farmers, technological options were selected at each benchmark sites (table 2).

**Table 2.** Number of farm households involved in the participatory rural appraisals (PRAs) and on-farm agronomic/animal feeding and manuring trials in benchmark sites in years 1999 to 2001.

| Country | Benchmark site | Participatory Rural Appraisals | | | Agronomic/livestock feeding trials | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | in 1999-2000 | | | in 1999 | | | in 2000 | | | in 2001 | | |
| | | IFAD* | Other** | Total | IFAD* | Other** | Total | IFAD* | Other** | Total | IFAD* | Other** | Total |
| Burkina Faso | Dori | - | 101 | 101 | | 5 | 5 | | 47 | 47 | | 98 | 98 |
| | Saria, | - | 205 | 205 | | 24 | 24 | | 45 | 45 | | 60 | 60 |
| Mali | Ségou, | - | 110 | 110 | | 13 | 13 | | 39 | 39 | | 39 | 39 |
| | San, | 93 | - | 93 | 3 | | 3 | 9 | | 9 | 9 | | 9 |
| Niger | Diffa/Tahoua | 122 | - | 122 | | | | | 32 | 32 | 8 | 22 | 228 |
| | Tillabéry | 51 | 532 | 582 | | 12 | 12 | | 312 | 312 | | 172 | 175 |
| | Gaya/Maradi | 87- | - | -87 | | 53 | 53 | | | | | 220 | 220 |
| | Kollo | - | - | - | | 7 | 7 | 105 | | 105 | | 16 | 16 |
| Senegal | Diourbel, | 160 | | 160 | | | | 15 | | 15 | 15 | | 15 |
| **All sites** | | **513** | **948** | **1461** | **3** | **114** | **117** | **129** | **475** | **624** | **32** | **627** | **659** |

* Farmers in IFAD investment project zone ** Farmers in other locations

Starting in1999, these options were tested through on-farm and on station trials. Priority was given to options that integrated crop, soil fertility and livestock production components, and thus addressed the whole crop-livestock nutrient cycling. Among the livestock production commodities tested were included cattle and sheep fattening, cattle and goat dairy, maintenance of bulls and oxen, and cow reproduction (table 3). Depending on the specificities of the production system at each benchmark site, the livestock commodity targeted was associated to one or several soil fertility practices which included the application of livestock manure transported from the barn or paddock to the field, the direct corralling at night of animals onto the field, the application of compost made of animal excretions and other organic wastes and some inorganic fertilizer, and the application of other organic material as mulch including cereal stovers. All these organic amendments were combined with some nutrient inputs either as supplement given to the animal, or to fertilizer added to the amendment combined or separated from the organic source. These amendments were applied to fields either devoted to the main staple food: millet, sorghum or rice, or to a dual purpose crop such as sweet sorghum in Mali, cowpea in Burkina Faso and in Niger, and ground nut in Senegal. An attempt was also made to apply compost to a forage grass, the 'burgu', Echinochloa stagina, cropped under irrigation in Niger. Trial were also made in four countries (only Niger reported), to improve the protein diet of small ruminants by planting browse species grown in small fodder banks

**Table 3**. Integrated livestock-soil management-crop options tested in the benchmark sites of the Nutman project 1999-2001

| Country | Benchmark site | Integrated livestock-soil-crop options | | |
|---|---|---|---|---|
| | | Livestock | Soil management | Crop |
| Burkina Faso | Dori | Fattening sheep | Compost ± phosphate | Sorghum |
| | | Dairy goat | Manure application | Millet-Cowpea |
| | Saria, | Fattening sheeps | Compost enriched | Sorghum |
| Mali | Ségou, | Diary cow | Manure ± Phosphate | Sweet Sorghum |
| | | Fattening cattle | Manure | Millet Cowpea |
| | San, | Diary cow | Manure ± Phosphate | Sweet Sorghum |
| Niger | Diffa/Tahoua | Fattening sheep | Manure application (Zaï) | Millet cowpea |
| | Tillabéry | Cow reproduction | Corralling ± fertilizers | Millet cowpea |
| | Gaya/Maradi | Fattening sheep | Manure application | Millet cowpea |
| | Kollo | Dairy cow | Compost ± Phosphate | Rice, Burgu |
| | | Fattening Cattle | Compost ± phosphate | Rice |
| | | Goats maintenance | Manure application | Browse Fodder bank |
| Senegal | Diourbel, | Cattle maintenance | Manure ± Phosphate | Millet- Groundnut |

The integrated options can be grouped into 11 groups (13 in table 3 because two options were repeated in two benchmark sites each) and read as follow:

1. Sheep fattening to value local fodder and feed inputs, associated to making compost of feces and feed refusals and applying these organic and fertilizer amendments to sorghum-millet-cowpea associated crops. Sites of Dori and Saria.
2. Goat dairy production to value local fodder and feed inputs. The excretions are collected to manure millet-cowpea, Site of Dori.
3. Cow dairy production valuing local feed resources and a newly introduced dual purpose cereal: the sweet sorghum which is cropped on lands amended with manure improved with local rock phosphate (Tilemsi), Sites of Ségou and San.
4. Cattle fattening valuing local fodder resources: rice straws improved with local and external inputs, excretions and refusals collected and applied as manure on millet-cowpea. Site of Ségou.
5. Improvement of reproduction performances of cattle through strategic supplementation in energy, protein and minerals for cows either transhumant or sedentary. Optimisation of the improved quality manure applied by corralling to millet-cowpea fields. Efficiency of corralling is improved by controlling rate of application, association with bedding-mulch or with simultaneous or relay placed inorganic fertilizer (DAP/NPK). The production of millet-cowpea associated crop is further enhanced by adapted soil tillage, sowing density, crop geometry and insecticide treatments. Site of Tillabéry.
6. Sheep fattening to value local feed resources, especially cowpea haulms and millet bran and also by the use of mineral licks from local sources corrected for their mineral composition. The production of millet-cowpea associated crops being enhanced by the use of animal manure, especially placed (Zaï) in association of not with inorganic fertilizers Sites of Diffa-Tahoua, Tillabéry and Gaya-Maradi.
7. Steers and oxen fattening valuing rice straws and wheat bran available in the peri-urban zone of Niamey. The cattle excretions are recycled in the make of compost enriched with local rock phosphate which is applied to irrigated fields of rice and Burgu grass (Echinochloa stagina).Sites of  Kollo and Tillabéry.
8. Enhancing dairy production of cows in the peri-urban area of Niamey by valuing rice straws and the agro-industrial by products available (wheat bran, brewery draff, urea licks). The cow excretions are recycled in the make of compost enriched with local rock phosphate that is applied to irrigated fields of rice and Burgu grass (Echinochloa stagina). Sites of Kollo and Tillabéry.
9. Improvement of the weight performance of cattle and draft oxen by a strategic supplementation in energy, protein and minerals, especially phosphorus, which will also improve the nutrient quality of the manure used in the millet-groundnut association. Site of Diourbel.

The diversity of situations encountered across the benchmark sites, the cross exchange of information and the discussions that they generate, constitute a major advantage of this collaborative project. This advantage was further strengthened by the large number of farm and rural communities involved  (Table 2) either in the socio-economic surveys or in the integrated crop-soil management-livestock trials.

## III. Summary of activities 1999-2001

### 1. Sites in Burkina Faso

### 1.1. Farming systems and benchmark sites of Burkina Faso

Two benchmark sites were selected in Burkina Faso to represent the farming systems of the semi-arid zone. The first site was Lelly, a village of 1643 inhabitants located in the northern part of the country about 100km from Dori (Table 1). Lelly climate is typical sahelian, the land is quite flat with a relatively large proportion of flat valleys (40%) with loamy-clay soils. The second one first was Namanéguéma, a village of 2633 inhabitants located in central Burkina Faso at 7km of Sabou, in the Saria region about 35 km from Koudougou and is located in a relatively wetter part of Burkina Faso. The land is part of the Mossi low altitude plateau covered by typical northern soudanian vegetation with parkland of Karité (Butyrospermum parkii) and Néré (Parkia biglobosa) trees.

In both sites, the main economic activities involve cropping and livestock husbandry, with a large variation in assets between households, especially in Namanéguéma were livestock distribution is extremely skewed. The main staple crop is sorghum in both sites, associated to by some millet in Lelly and maize and low land rice in Namanéguéma. Secondary crops include groundnut, voandzu, a local legume, cowpea, sesame and sorel. According to the farmers interviewed, on the average, crop yields cover household food requirements in 85% of the farms in Lelly and only 34% in Namanéguéma. Fertilizer inputs are minimal and used by a small minority of farmers, but manure is commonly applied to soils that are deemed infertile (Table 4). Manure is either applied after collection of manure in the corrals or pens and transport, or directly deposited by animals corralled at night on the cropland, or less included into compost. Other organic material and house wastes were also used as mulch. Soils were amended building of anti-erosive stone contours, and through crop association and rotation.

**Table 4.** Proportion (%) of cultivated land with soil fertility problem by wealth category and gender in study villages in Burkina Faso

| Wealth category | Village | | | |
|---|---|---|---|---|
| | Namaneguéma | | Lelly | |
| | Men | Women | Men | Women |
| High | 70-90 | 90-100 | 50-80 | 70-80 |
| Medium | 80-100 | 100 | 60-75 | 70-100 |
| Low | 100 | 100 | 100 | 80-100 |

In both sites, the ruminant species most frequently bred was goats which are mainly bred for meat but some farmers in Lelly also milked them. Farmers in Lelly were more involved in sheep fattening during the dry season, using crop stovers (36.7%), especially sorghum stover, cowpea or groundnut haulms (24.4%), millet or sorghum bran (23.7%). Purchased feed supplements are restricted to a few agricultural by-products used in sheep fattening (3.9% mainly wheat bran, cotton seeds or cakes and sodium salt). Women do not have specific land rights but do own and raise livestock, especially small ruminants. In Lelly, large amounts of forages were seasonally stored to feed fattened animals (25.8%), and also pregnant and lactating females (30.0%), animals in poor condition (13%) and oxen and bulls (16.4%) these inlcude 10.4 t of sorghum stover, 1.65 t of bush hay, and 0.63 t of legume haulms in average per farm. Grazing resources are managed communally with free access after crop harvest. Seasonal movement of herds were limited, most of them within the village territory, away the village and croplands during the late wet season. In Lelly, a few foreign herds stayed for short periods during the dry season and contributed to manure some farmers fields on a contractual basis.

In Namanéguéma, poultry is important with an average of 13 chicken or guinea fowls per farm. There are some pigs (278) and cattle distribution among farms is extremely skewed (table 5), small ruminants are better shared with a large domination of goats. Most small ruminants are tethered during the wet season and left free ranging and receive small amounts of supplement feed mostly produced on the farm (sorghum stover and haulms).

As part of the participatory rural appraisal (PRAs), farmers stratified themselves into three distinct wealth categories based on human, land and livestock assets (table 5).

**Table 5** Average resource endowments by class category  in study villages in Burkina Faso

| Bench mark site | Villages | Category | Labor (adult equiv.) | Cropped Area (ha) | Cattle (head) | Sheep (head) | Goats (head) | Nature of the development Project |
|---|---|---|---|---|---|---|---|---|
| Dori | Lelly | High | - | - | 9 | 10 | 12 | UFC[1], PEF[2], PSB/GTZ[3], IFAD sorghum-millet breeding |
| | | Medium | - | - | | | | |
| | | Low | - | - | | | | |
| Saria | Namané-guéma | High | 9.2 | 3.3 | 9.1 | 17.3 | 21.7 | GRN/SP*, PDISAB** and district offices of the Livestock Resource Dept |
| | | Medium | 4.8 | 5.5 | 0.0 | 4.0 | 11.4 | |
| | | Low | 7.2 | 1.9 | 0.0 | 0.9 | 3.6 | |

1 UFC Union Fraternelle des Croyants (Muslim NGO)
2 PEF Projet Economie Familiale
3 PSB/GTZ, Projet Sahel Burkinabé funded by GTZ
* GRN/SP INERA: Research programme on Natural Resource Management and Production Systems.
** PDSIAB: Programme de Développement Intégré des provinces du Sanguié et du Bulkiemdé.

Using average food self-sufficiency defined as the number of months a household could meet its food requirements from its own farm output as a criterion, a large proportion of households in Namaneguéma (66.4%) ranked low in food self-sufficiency, whereas the situation in Lelly is much better (Table 6).

**Table 6**. Food self-sufficiency by wealth categories in villages studies in Burkina Faso,

| Wealth category | Village | | | |
|---|---|---|---|---|
| | Namaneguéma | | Lelly | |
| | Proportion of total households (%) | Number of months food needs are covered | Proportion of total households (%) | Number of months food needs are covered |
| High | 14.0 | 8 | 31.7 | 11 |
| Medium | 19.6 | 5 | 28.7 | 11 |
| Low | 66.4 | 3 | 39.6 | 9 |

In terms of social institutions, farmers in Lelly have grouped themselves into four farmers associations, among which to are women associations, and youth have their own association, all this in addition to the two traditional community institutions. In Namanéguéma, there are three associations including a farmer-men, a women and a scholar parents associations.

### 1.2. Technological options for more efficient crop-livestock integration

Declining soil fertility was recognized as a major constraint to the productivity of the farming systems in the study villages. At both sites farmers have their own indicators of soil fertility that include soil surface features (type of crust, denudated patches), poor seedling development, poor yields, panicule malformations and weed species composition. These indicators are specific of soil types. The main methods of soil fertility improvement cited by farmers in the two benchmark sites are shown in Table 7. The production, collection, and application of manure and composting were the two interventions selected by the farmers as most promising ways to improve soil fertility.

**Table 7**. Principal methods of soil fertility improvement by wealth category and gender in study villages in Burkina Faso

| Method | Village | | | |
|---|---|---|---|---|
| | Namaneguéma | | Lelly | |
| | Men | Women | Men | Women |
| Corralling of animals in field | - | - | H, M, L | H, M |
| Collection/ spreading of manure | H, M | H | H, M, L | H, M, L |
| Use of inorganic fertilizer | H, M | - | H, M | - |
| Fallowing | H, M, L | - | H, M | - |
| Crop rotation | H, M, L | - | H, M, L | - |
| Use of compost | H | - | H | - |
| Use of appropriate inter-crops | - | - | H, M, L | H, M, L |
| Construction of dikes | H, M | - | H, M | - |
| Use of dry crop residues | H, M | H, M, L | - | - |

H, M and L refer to High, Medium and Low wealth categories, respectively.

The production of manure links soil fertility to livestock production. Farmers recognized livestock nutrition as an important area for intervention, after animal health. Farmers also identified appropriate and profitable feeding strategies for livestock fattening as a key issue in animal production because of the economic benefits and link with compost production. Compost making from crop stovers, feed refusals and livestock feces associated with sheep fattening and improved feeding of dairy goats constituted the technological package tested by farmers in Lelly, while the same package without dairy goats was tested by farmers in Namaneguéma.

### 1.3. Ex-ante economic impact assessment

Ex-ante marginal cost analysis of the use of compost either alone or in combination with inorganic fertilizers increased sorghum grain and stover yields, but the net benefits after taking into consideration the cost of inputs remain modest, particularly in the northern zone, resulting in negative marginal returns in some cases. Compared with a situation where no soil amendment was applied, compost plus 50 kg $ha^{-1}$ of urea gave the highest marginal returns in Namaneguema (Table 8). while the use of compost alone gave the highest marginal returns in Lelly,

**Table 8.** Marginal analysis of the use of compost on sorghum crop in Namaneguéma, central Burkina Faso and in Lelly, northern Burkina Faso

A) Namaneguéma

| Technical and economic parameters | Crop technologies and inputs (kg ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | 1 Control: No input | 2 Compost | 3 Compost + 100 NPK | 4 Compost + 50 Urea | 5 100 NPK | 6 50 Urea |
| Grain (CFA) | 81000 | 270000 | 360000 | 390000 | 180000 | 210000 |
| Stover (CFA) | 10500 | 14000 | 17500 | 20000 | 12500 | 13500 |
| Gross product (CFA) | 91500 | 284000 | 377500 | 410000 | 192500 | 223500 |
| Total cost (CFA) | 25000 | 110600 | 117000 | 142000 | 138500 | 138500 |
| Net benefit (CFA) | 66500 | 173400 | 204100 | 268000 | 54000 | 85000 |
| Marginal rate of return (%) | - | 125 | 150 | 172 | -11 | 16 |

Compost was applied at the rate of 5 t DM ha$^{-1}$

B) Lelly

| Technical and economic parameters | Treatments (kg ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | 1 Control: No input | 2 Compost | 3 Compost + 100 NPK | 4 Compost + 50 Urea | 5 100 NPK | 6 50 Urea |
| Grain (CFA) | 77440 | 94808 | 116960 | 98400 | 92400 | 89840 |
| Stover (CFA) | 26370 | 38624 | 45000 | 31995 | 30780 | 30450 |
| Gross product (CFA) | 103810 | 133432 | 161960 | 130395 | 123180 | 120290 |
| Input cost (CFA) | 0 | 18000 | 42000 | 30000 | 24000 | 12000 |
| Net benefit (CFA) | 103810 | 115432 | 119960 | 100395 | 99180 | 108290 |
| Marginal rate of return (%) | - | 64.6 | 38.5 | -11.4 | -19.3 | 37.3 |

Compost was applied at the rate of 5 t DM ha$^{-1}$

The ex-ante marginal analysis of sheep fattening trials in Namaneguema showed that compared to current farmer practice of leaving animals to scavenge for their nutritional needs, feeding sheep a combination of concentrates and pounded *Piliostigma* pods can give a marginal rate of return of 50% and is the best option out of the different treatments tested in this experiment (Table 9).

**Table 9**. Marginal analysis of sheep fattening trials in Namaneguema, Burkina Faso.

| Technical and economic parameters | Treatments (kg d$^{-1}$) | | | |
|---|---|---|---|---|
| | 1 Control: Farmer practice | 2 Stover ad libitum + 30 % concentrate | 3 Stover ad libitum + 10% concentrate + 50% Piliostigma pods | 4 Stover ad libitum + 60% concentrate |
| Weight gain (CFA) | 9918 | 13122 | 13032 | 13980 |
| Manure (CFA) | 301 | 270 | 247 | 180 |
| Gross product (CFA) | 10219 | 13392 | 13279 | 14160 |
| Input cost (CFA) | 7390 | 10055 | 9410 | 10560 |
| Net benefit (CFA) | 2860 | 3337 | 3869 | 3600 |
| Marginal rate of return (%) | - | 18 | 49 | 23 |

The concentrate is made up of 38% cotton seed cake and 62% wheat bran.

## 1.4. Project implementation, trials and results

### Dori benchmark site, the village of Lelly

Surveys conducted in 1999 in villages near Dori identified farmer' practices of feed supplementation for cattle, fattening sheep and dairy goats, especially the use of sorghum stovers. The survey included the assessment of available feed resources at the village scale. Parallel survey was carried out on farmer' practices in soil fertility management which highlighted the interest of farmers on composts. Finally trials were designed for improved nutrition of fattened sheep, dairy goats and improved quality compost made of the excretions of these animals, testing the effect of its application on a sorghum crop.

<u>Sheep fattening</u>

Nutrition trials with fattening sheep were initiated in 1999 with 60 rams which received either the 'farmer diet' or a 'recommended diet' during 60 days. The larger weight gains obtained with the recommended diet were not significantly different from farmer'diet (84 53 versus 98 55) because of the high heterogeneity of the animals within treatment. Weight gain decreasing with the age and size of the animal.

In 2000, a sheep fattening trial was carried out for 70 days on 98 rams owned by 47 farmers, among which 22 were women. Two diets were compared to the standard feeding practice of the farmers who rely on sorghum stalks, cowpea haulms and millet bran (20 to 30% of daily intake ). One diet included crop stovers offered *ad libitum* (150% of intake) and 26% of DM intake as cotton seed cake (375 to 500 g $d^{-1}$) per animal while the second diet restricted crop residues to 50 % of that given in the first treatment and included 40% of DMI as cotton seed cake (625 to 750 g $d^{-1}$ per animal). Liveweight gain, feed refusal and feces output were determined and used in economic analysis.
Sheep weight gains of fattened rams increased with the proportion of cotton seed cake from 64.8 ±35.4 g $d^{-1}$ for the control, to 71.7 ± 36.9 and 81.0 ± 29.0 g $d^{-1}$ for the rams receiving 26% and 40 % of their diet as cotton seed cake, respectively. The initial weight of the rams also influenced their performance, the gains being larger for lighter animals: animals between 20-30kg live weight at the onset of the fattening gained 80.5 ± 56.3 g $d^{-1}$, while rams of 31 to 40 kg gained 77.8 ± 39.5 and rams of 41 to 50 kg only gained 66.5 ± 22.3 g $d^{-1}$. Also, sheep fattening managed by women (79.8 ± 50.1 g $d^{-1}$) on average performed better than the ones managed by men (71.4 ± 30 g $d^{-1}$). Average fecal output harvested by farmers and included in the compost was 300 g DM $d^{-1}$ per animal.

In 2001, in spite of the project financial difficulties, 62 farmers of Lelly, among whom 30 women, initiated a fattening trial with 274 sheep first weighed and allotted in November 2001. The number of sheep fattened differed between women farmers who had 4± 3 animals while men had 7± 4 animals. The trial ended the 15 of February 2002, just prior to the Tabaski Muslim festival. Out of four possible diets, two diets were compared by each farmer. The standard feeding practice of the farmers included on sorghum stalks, cowpea haulms and millet bran and locally made urea lick. The alternative diets included in addition either cotton cakes (25 to 30% of daily dry matter intake); wheat bran (25 to 30% of daily DM intake) or half of each. Liveweight gain, feed refusal and feces output have been measured determined and used in economic analysis. The average daily weight gains recorded were 98±56, 119±53, 116±61 and 128±52 g $d^{-1}$ respectively. The average performances calculated for each farmer gender gave 110±61 for women versus 117±63 g $d^{-1}$ for men. An ex-post economic assessment was done.

Dairy goats

In a first experiment carried out in 1999 in the village of Katchari protein and mineral supplemented diets were tested on 3 lots of 12 dairy goats grazing for 8 hours daily. The supplements were composed of 600 g of sorghum stover, chopped or not, plus 200g of cotton cake and, in one of the 3 lots, animal had access to mineral blocks. The addition of mineral lick to a supplementation based on sorghum stover and cotton cake only increased marginally milk production of dairy goats (0.596 kg $d^{-1}$ versus 0.580 and 0.587 kg $d^{-1}$ ) but allowed the goats to keep their weight (+ 0.04 g $d^{-1}$ )instead of losing condition (- 22.31 and - 28,70 g $d^{-1}$ ). This result was attributed to increased feed intake with mineral supplements, indeed sorghum intake was 33.8 gDM $kg^{-0.75}$ for goats that had access to licks versus 30.0 and 26.6 g DM $kg^{-0.75}$ for the other goats.

In 2000, a feed supplementation trial was conducted on lactating goats both on station, with 36 doe-kid pairs and on-farm with 62 doe-kid pairs, owned by 15 farmers. In both cases, goats were grazed and the treatments consisted in comparing the use of a locally made, urea and millet bran lick (estimated cost 1 CFA per animal per day), to the use of an industrially made lick complemented by 100g $d^{-1}$of cotton seeds (estimated cost 15.5 CFA per animal per day). On station, total milk produced was estimated by double weighing three times a day, while on-farm only milk that was collected by the farmer was measured. Weight of does and kids were monitored, as was fecal production.
The results of supplementation of lactating goats with locally made urea lick compared very well with results obtained with industrially made mineral licks plus 100g of cotton seed per day. The milk yield of the does and weight changes of both does and kids were slightly higher with the industrial lick (Table 10), but the differences are not sufficient to cover the additional cost. Live weight losses of does during the 84 days of monitoring were much more severe on-station than on-farm. Similarly the live weight gains of the kids were larger on-farm than on station.

**Table 10**. Effects of supplementation trials on milk yield and weight changes of lactating does and kids, northern Burkina Faso, 2000.

| Performance expressed per day | On-station (Katchary) | | On-farm (Lelly) | |
|---|---|---|---|---|
| | Urea-made lick | Industrial lick + 100g $d^{-1}$cotton seed cake | Urea-made lick | industrial lick + 100g $d^{-1}$cotton seed cake |
| Lick consumption (g) | 8 | 12 | - | - |
| Milk milked (g ) | - | - | 123±78 | 143±79 |
| Total milk (g) | 387±183 | 406±178 | 280-416 | 324-408 |
| Doe weight changes (g) | -44.4±14.2 | -28.2±13.3 | -8.4±26.7 | -1.0±20.2 |
| Kid weight gains (g) | +44.1±12.6 | +45.4±10.4 | 67.3±20.8 | 65.5±19.6 |

In March 2001, an on-farm feed supplementation trial was initiated on 80 doe-kid pairs, owned by 15 farmers. Out of four possible dietsn each farmer implemented and compared two. All goats were grazed, in the three alternative feeding treatment they had also access to a locally made, urea and millet bran lick (estimated cost 1 CFA per animal per day), in one of the treatment they were fed in addition 150g $d^{-1}$ of wheat bran and in the last diet to 150 g $d^{-1}$ of cotton cake. Collected milk was measured and the weight of does and kids were monitored, as was fecal production. Unfortunately, the experiment was stopped after a month because of lack of cash to pay for the supplements. In spite of the short duration of the trial, access to locally made urea lick increased milk yield and kids liveweight gain (table 11) while additional cotton cakes mainly enhanced mild yields while additional wheat bran did not improved nor milk yield nor kid growth.

**Table 11.** Effects of supplementation trials on milk yield and weight changes of kids, in March-April 2001, in Lelly, northern Burkina Faso.

| Feeding treatments | milk collected g $d^{-1}$ | | Kid liveweight gain g $d^{-1}$ | |
|---|---|---|---|---|
| | mean | s.d. | mean | s.d. |
| Grazing | 66 | 20 | 32.2 | 20.9 |
| Grazing + Urea lick | 89 | 39 | 51.7 | 27.5 |
| Grazing + Urea lick + 150g wheat bran | 84 | 22 | 49.1 | 24.4 |
| Grazing + Urea lick + 150 g cotton cakes | 112 | 47 | 54.5 | 33.5 |

Compost making and application to sorghum crop

In 1999, compost was experimentally produced by 5 volunteer farmers of Lelly in pits 5 m long and wide and 0.7 m deep, using a mix of forage leftover by fatten sheep, manure and local rock phosphate. This compost was applied at a rate of 5t DM $ha^{-1}$ to a sorghum crop. Compost application increased stover yield by 107% and grain yield by 40% compared to a control with no inputs.

In 2000, 18 farmers got involved, and dug pits which the filled with the feed refusal from the fattening trial, the feces produced by the animals kept in the compound, and local rock phosphate. The effect of the compost was then tested on sorghum cropped with of without compost (at 5t DM $ha^{-1}$), associated or not to either 100 kg $ha^{-1}$ of NPK 15-25-15, or to 50 kg $ha^{-1}$urea. The inorganic fertilizers were also used alone, without compost. The average production of compost was 2937 kg (fresh weight) per 5x3x0.7m pit. Because of the poor distribution of the rains, the yields of sorghum were below average. However; declines in yields were less for the sole compost application than for inorganic fertilizer applied either alone or in combination with compost (Table 12). Ex-post economic assessment were only done for sole compost technology.

**Table 12**. Average sorghum grain and stalk yield from on-farm compost and inorganic fertilizer application trials, Lelly, Burkina Faso, 2000.

| Treatments | | Sorghum yields (kg DM $ha^{-1}$) | | | |
|---|---|---|---|---|---|
| Compost | Fertiliser | Grain | | Stalks | |
| ( t $ha^{-1}$) | (kg $ha^{-1}$) | Mean | S.E. | Mean | S.E. |
| 0 | 0 | 258 | 143 | 1475 | 739 |
| 5 | 0 | 436 | 317 | 1560 | 180 |
| 5 | 100 NPK | 304 | 86 | 1547 | 710 |
| 5 | 50 Urea | 305 | 126 | 1878 | 258 |
| 0 | 100NPK | 103 | 88 | 1700 | 985 |
| 0 | 50 Urea | 146 | 37 | 1066 | 191 |

Forage resources availabilities were assessed through the year 1999 for the village of Lelly including herbaceous and browses in rangelands, as well as crop residues and fodder crops. In northern Burkina Faso, three major land types offered contrasted yields (from 1,44 ± 1,38 to 3,20 ± 1,20 t DM $ha^{-1}$), species composition and forage value for the rangelands they supported. Among the browses, Acacia species and *Pterocarpus lucens* contributed most and croplands produced 3,92 ± 1,56 t DM $ha^{-1}$ of sorghum stover, 3,40 ± 0,92 t DM $ha^{-1}$ of millet stover and about a 1 t DM $ha^{-1}$of cowpea haulms.

During the dry season 2000, the mass of millet or sorghum residues left in the fields decreased from 1205±636 kg DM ha $^{-1}$ in December, after the harvest, to 452 ±234kg DM ha $^{-1}$ in May, just before land preparation for the new crop. This 62% disappearance rate was not linear with maximum disappearance in December and slower disappearance thereafter. Fecal depositions during that season totaled 484±515 kg DM ha $^{-1}$, indicating some return of organic matter and nutrients by livestock to the cropped areas.

**Benchmark site of Saria, the village of Namanéguéma.**

An initial survey was conducted in 1998 in the central Plateau of Burkina Faso on farmer's soil fertility management practices, available feed resources and sheep fattening diets. Compost ranked high among the potential practices to improve soil fertility and sheep fattening was recognized as a potential profitable enterprise open to many farmers including women. Indeed the survey indicated that returns from small ruminants husbandry contributed to 65% of the annual income of farmers. It was thus decided to concentrate demonstration trials on these technologies combined.

Sheep fattening

A sheep fattening trial was carried out with 24 farmers during 90 days, targeting the Tabaski market in March 1999. Fifty six male sheep were subdivided into two groups. Both were fed roughages ad libitum and small amount of cowpea, dolichos and groudnut haulms, and in addition, one group was fed wheat bran at 20% and the other at 40% of feed dry mater requirements calculated for each animal. The diets that included wheat bran concentrate at 40% of feed dry mater requirements was more efficient and profitable than the diet that only included wheat bran at 20% of the requirements (table 6). In addition to weight gains, 18kg of feces and feed refusal were collected per animal during the 90 days of fattening and were recycled in compost.

In 2000 the sheep fattening trial expanded to 36 farmers, including 11 women, from Namaneguéma, and involved 85 sheep over 70 days. Three diets were tested. They included 10, 30 or 60% of a supplement made of cottonseed cake (38%) and wheat bran (62%), while the rest of the diet consisted of 28% cowpea hay and 50% pounded *Piliostigma* pods in one case, 17% cowpea hay and sorghum straw *ad libitum* in a second case, and just sorghum straw *ad libitum* in a third case. Question the design it is poorly described and I cannot figure it out. Liveweight gains, feed refusals, excretions and labor inputs were measured. Local market prices were also collected for profitability assessment. The best weight gains were observed for the treatments with the highest rate of concentrate in the diet (60%). Small sheep benefited better from the addition of 50% grounded pods of *Piliostigma reticulata* than large sized ones. Daily fecal production of sheep tethered for fattening ranged between 457 and 643 g DM d$^{-1}$ and were included in the compost.

Compost making and application to sorghum and cowpea crops

In 1999, 24 farmers volunteered to test compost making and use on sorghum and cowpea. They dug a 3 x 3 x 1 m pits during the dry season and prepared compost from farm produced manure, feed refusal, house wastes and Burkina Phosphate. The compost produced was used in a comparative trial with either 4 or 5 t ha$^{-1}$ of compost were applied to four plots of 500 m$^{-2}$ on two breeds of cowpea and sorghum (on being the local land race). A late start of the rains followed by floods in August resulted in poor yields of cowpea beans tested as associated crops with sorghum but they clearly indicated the superiority of one of the breed (KVX386-4-5-2D) who produced 274 to 423 kg ha$^{-1}$.

In 2000 the compost trial expanded to 45 farmers of Namaneguéma. Soil fertility trials differed among farmers. One group of farmers compared the effects of 5 t $ha^{-1}$ of compost applied every second year to the effects of 4 t $ha^{-1}$ every year in pure stands of sorghum Sariasso 14 or cowpea KVX 414-222-2. Another group tested the same inputs on two other varieties: sorghum ICSV 1042 and cowpea KVX 61-1. Other farmers applied 5t $ha^{-1}$ of compost plus 100 kg NPK and compared it with sole inorganic fertilizer application of 100 kg $ha^{-1}$ NPK, 50 kg urea and 200 kg rock phosphate. Finally, the last group applied inorganic fertilizer (100 NPK + 50 urea + 200 rock phosphate kg $ha^{-1}$) compared one-to-one line association of sorghum and cowpea to pure stands of each crop. The variables measured included amount of compost produced by each farmer, chemical characteristics of soil and compost, yield of millet and cowpea grain and forage. The amount of compost produced by farmer ranged between 900 and 1100 kg fresh material for a pit, which only allow to manure a restricted area cropland.

In 2000, the crop trials indicated yield superiority of sorghum variety ICSV1042 over Sariasso14 and of cowpea variety KVX 414-22-2 over KVX 61-1. Because of poor and ill distributed rainfall in 2000, overall yields were low. However, based on the total grain yield of sorghum and cowpea (Table 13) combined application of compost, NPK, urea and rock phosphate ranked superior to inorganic fertilizer and other compost application, sole or with NPK only.

**Table 13.** Yield effects of on-farm soil fertility trials in Namanéguéma, Burkina Faso, 2000. Sorghum breed: Sariaso 11, cowpea breed IAR7.
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| Treatments | Yields kg $ha^{-1}$ Sorghum + cowpeagrainz |
|---|---|
| 5 t $ha^{-1}$ compost | 631 |
| 4 t $ha^{-1}$ compost | 402 |
| 5 t $ha^{-1}$ compost + 100 NPK | 610 |
| 5 t $ha^{-1}$ compost + (100 NPK + 50 urea + 200 rock phosphate) | 1145 |
| 100 NPK + 50 urea + 200 rock phosphate | 580 |

The same experiment was repeated in 2001 with 60 farmers.. Better rain disutribution favor crop growth although the experiment was settled late in the season. Higher yields were obtained with the combined application of inorganic fertilizers. (table 14).

**Table 14**. Yield effects of on-farm soil fertility trials in Namanéguéma, Burkina Faso, 2000. Sorghum breed: Sariaso 11, cowpea breed IAR7.
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| Treatments | Yields kg $ha^{-1}$ | | | |
|---|---|---|---|---|
| | Sorghum grain | Sorghum stover | Cowpea grain | Cowpea haulms |
| 5 t $ha^{-1}$ compost | 196 | 435 | 365 | 422 |
| 4 t $ha^{-1}$ compost | 196 | 387 | 311 | 376 |
| 5 t $ha^{-1}$ compost + 100 NPK | 171 | 353 | 288 | 323 |
| 100 NPK + 50 urea + 200 rock phosphate | 225 | 480 | 471 | 582 |

### 1.5. Discussion and ex-post economic assessments

Farmers are using a large array of feed to fatten sheep, including roughages such as bush hay, browses, but also crop residues, especially sorghum stovers, and concentrates such as cotton cakes, which contribute to 20 to 30% of the diet. Weight gain performances are very variable with the age and size of the animal, the duration of the fattening. Best results are obtained with animals less than 18 month of age. An economic assessment was done ex-post of the farmer trial that involve 62 farmers and 274 sheep in Lelly in 2001 (Table 14b)

**Table 14b:** Ex-post economic assessment of farmer sheep fattening technologies (Lelly, 2001)

| Average per sheep of parameters measured over 62 days of fattening period | Farmer practice Including urea lick | Cotton cakes + urea lick | Wheat bran + urea lick | ½ cotton cake ½ wheat bran + urea lick |
|---|---|---|---|---|
| Weight gain (g $d^{-1}$) | 98±56 | 119±53 | 116±61 | 128±52 |
| Sheep sale price (CFA) | 30710 | 35281 | 29516 | 32345 |
| Manure sale price (CFA) | 99 | 99 | 109 | 105 |
| **Gross product (CFA)** | **30809** | **35380** | **29625** | **32460** |
| Sheep purchase price (CFA) | 12950 | 12850 | 12860 | 13740 |
| Feed costs (CFA) | 7890 | 8076 | 8076 | 8076 |
| **Total variable cost (CFA)** | **20840** | **20926** | **20936** | **21816** |
| Net benefit (CFA) | 9969 | 14454 | 8689 | 10644 |
| Marginal rate of return (%) | NA | 5215 | D | 69 |

The economic profitability depends largely on the market situation and on the trade ability of the farmer. Yet diet proposed by the research could enhance the weight gain by 30% and the profitability by 45% in Lelly, and by 93 to 229% in Namanéguéma with gross margins of 8000 to 15000 CFA per animal (Table 14c). However, the enterprise is limited by the capital that needed to be invested in bying the lean animals (only 22% of the sheep fattened originated the farmer herd) and some of the feed supplements.

**Table 14c.** Ex-post economic assessment of farmer sheep fattening technologies in Namaneguema, Burkina Faso (2002)

| Average technical and economic parameters (CFA) Per sheep and for 70 days of fattening | Treatments (kg $d^{-1}$) | | |
|---|---|---|---|
| | Control: Farmer practice | Stover ad libitum + 10% concentrate + 50% Piliostigma pods | Stover ad libitum + 30% concentrate |
| Initial animal weight | 20 | 20 | 17.7 |
| Weight gain | 1.03 | 6.75 | 7.00 |
| Sale price | 8410 | 21358 | 18865 |
| Manure sold | 0 | 108 | 115 |
| **Gross product** | **8410** | **21358** | **18865** |
| Buying price | 7000 | 10250 | 9000 |
| Feed cost | 0 | 781 | 970 |
| Vet. Care cost | 0 | 220 | 220 |
| **Total variable costs** | **7000** | **11251** | **10190** |
| **Net benefit** | **1410** | **10099** | **8675** |
| Marginal rate of return (%) | NA | 204.4 | 134.4 |

The concentrate is made up of 38% cotton seed cake and 62% wheat bran.

The supplementation of the dairy goat diet with urea licks enhanced intake of sorghum stover that was further increased with complementary mineral supplements. This higher intake (up to 35 g $d^{-1}$) reflected in the milk production and in attenuated weight losses of the dams. The cost of the protein supplement (100 to 200 g of cotton cakes) could easily be recovered by the sale of the milk but the return margins were narrower when a mineral lick was included (table 14c).

**Table 14c:** Ex-post economic assessment of farmer supplement feeding strategies for dairy goats (Lelly, 2001)

| Average per sheep of parameters measured over 84 days of goats milking period | Farmer practice: Grazing + local supplements | Supplemented with 100-200 g of cotton cakes | Supplemented with 100-200 cotton cakes + mineral lick |
|---|---|---|---|
| Milk extracted (g $d^{-1}$) | 89±39 | 84±22 | 112±47 |
| Milk sale price (CFA) | 1647 | 2520 | 3405 |
| Manure sale price (CFA) | 90 | 101 | 101 |
| **Gross product (CFA)** | **1737** | **2621** | **3506** |
| Feed cost (CFA) | 435 | 1134 | 1800 |
| Mineral supplement cost (CFA) | 0 | 0 | 280 |
| **Total variable cost (CFA)** | **435** | **1134** | **2080** |
| Net benefit per goat (CFA) | 1302 | 1487 | 1426 |
| Marginal rate of return (%) | NA | 26.5 | 7.5 |

Sorghum did respond to compost application by a 55% increase in grain and stover. However combined use of compost with inorganic fertilizer led to yield losses, thus only the use of 5t of compost was assessed economically (table 14d). The stovers are a major source of feed and are actively harvested by farmers (about 10 t per farm and per year in Lelly), only about 20% of stovers are returned to the soil, and the feces deposited by grazing animals average only 484 kg $ha^{-1}$ in cropped land. Altogether feces and residues returned only cover a small fraction of the nutrient exported by yields.

**Table 14d**. Ex-post economic assessment of the application of 5t $ha^{-1}$ of compost every two years on a sorghum crop in Lelly, Burkina Faso.

| Technical and economic parameters | Compost application (t $ha^{-1}$) | |
|---|---|---|
| | 0 | 5 |
| Grain sale price (CFA) | 41120 | 69760 |
| Stover sale price (CFA) | 22110 | 23400 |
| **Gross product (CFA)** | **63230** | **93160** |
| Cost of pit /year (CFA) | 0 | 7200 |
| Compost cost/year (CFA) | 0 | 19370 |
| **Total variable cost** | **0** | **26570** |
| Net benefit | 63230 | 66590 |
| Marginal rate of return (%) | NA | 12.6 |

The concentrate is made up of 38% cotton seed cake and 62% wheat bran.

The results obtained in Namanéguéma with the application of 4 or 5 t $ha^{-1}$ of compost sole or combined with two levels of inorganic fertilizer on associated sorghum and cowpea were convergent with the results obtained in Lelly as for the negative rentability in spite of the small gain in production (table 14e).

**Table 14e:** Ex-post economic assessment of the application of 4 or 5t $ha^{-1}$ of compost every two years with or without inorganic fertilizer on a sorghum-cowpea associated crop in Namaneguema, 2001.

| Average per hectare of parameters measured over a year associated crop | Farmer practice | 4t $ha^{-1}$ compost | 5t $ha^{-1}$ compost | 5t $ha^{-1}$ compost+100kg $ha^{-1}$ NPK | 100 kg NPK + 200 kg Rock P + 50kg Urea $ha^{-1}$ |
|---|---|---|---|---|---|
| Sale price of sorghum grain | 65000 | 88200 | 88200 | 76950 | 101250 |
| Sale price of sorghum stalks | 157500 | 311000 | 365000 | 288000 | 471000 |
| Sale price of cowpea grains | 6000 | 3870 | 4350 | 3530 | 4800 |
| Sale price of cowpea haulms | 7500 | 9400 | 10550 | 8075 | 14550 |
| **Gross product** | **236000** | **412470** | **388666** | **376555** | **591600** |
| Cost of sorghum seeds | 0 | 3600 | 3600 | 3600 | 3600 |
| Cost of compost | 0 | 26667 | 33333 | 34583 | 0 |
| Cost of fertilizers | 0 | 0 | 0 | 2500 | 30500 |
| **Total variable cost (CFA)** | **0** | **30267** | **36933** | **40683** | **34100** |
| Net benefit (CFA) | 236000 | 382203 | 431167 | 335872 | 557500 |
| Marginal rate of return (%) | na | 734.5 | 413.4 | D | D |

Among the difficulty encountered in on-farm research implementation was the heterogeneity of the animals fattened by the farmers in term of age, sex and breed. Measuring the milk produced by each individual goat in a dairy herd is difficult to organize in farmer's environment, and it is not always easy to quantify all inputs. Some of the inputs farmers are asked in purchase, or cost involved in their participation to the demonstration trial are heavy for their finance (case of the compost pits) and would require larger investments to be brought to operational scale (carts or wheelbarrow, rock phosphate and other mineral fertilizer). The very open communal grazing renders measures of feed uptake by livestock, as well as excretion deposition very cumbersome.

The research project implementation suffered from delays in getting the agreed funds to organize field activities. These delays have led to delays in sowing or in the initiation of the fattening and dairy trials reducing the technical performances and economic profitability of the tested technologies. Some trails had also to be cancelled (2001).

### 1.6. Pathways for adoption and diffusion

Several pathways for adoption and diffusion of the technologies tested by farmers were explored. In the villages where these trials were conducted, open days and field visits were organized as part of the technology evaluation process; to explain the results of the trials to the farmers and to seek their inputs on further refinement of the technologies. A survey was conducted in 2002 to fully document farmers perception of the technologies tested, including ranking of the technological options and listing of pro and cons of each options. The application of 4 or 5 t ha was ranked first by 63% of the Namanéguéma farmers, while the alternative use of 100 kg NPK was selected by 47 % and the use several chemical fertilizers was selected by 23% of the farmers. Similarly the use of cotton cake was ranked first by 100% of Lelly farmers, ahead of the mix of cotton cake and wheat bran (60%) and sole wheat bran (30%). Among the constraints identified by the farmers: the labour and material cost of the pit compost technology was highlighted, although 47% of the farmers surveyed declared ready to invest 15 000 CFA or more if necessary to adopt one of these technologies. Another constraint often cited was the difficult access to external inputs such as fertilizers, cotton cakes and wheat bran. Finally, the adoption of some of the technologies would require specific training as for the make of animal licks.

Another pathway to diffuse research results and technologies was through collaboration with development agencies, especially GRN/SP (soil fertility), PDISAB (forage conservation), the district agriculture and livestock departments (DRA/DRRA), the POE (feed supplementation) and the IFAD funded project on adapted millet and sorghum breeds. In 2000, women of the village of Lelly were invited to share their experience in sheep fattening with women associations meeting in Soum organized by the project PEF (Projet d'Economie Familiale). The project scientists were also invited to a two days workshop (AMRT) organized with the district agriculture and livestock department including a visit to Lelly. And the farmers of Lelly get an award for their success in the development of compost making and application in the framework of the promotion of a governmental policy that targets the building of 50 000 compost pits all over the country.

## 2. Sites in Mali.
### 2.1. Farming systems and benchmark sites in Mali

Farm surveys were carried out in central Mali in 1999. Participatory methods and group interviews were used to surveys natural resources and establish a farm typology based on resource endowment in 5 villages of which 3 were selected in the area of intervention of the IFAD funded project in San district, and two others in the district of Ségou. Village resource maps and nutrient status diagnostics were established with the farmers. The criteria defined with participation of the farmers were used to classify 252 farm across the five villages (table 15) and guided the sampling of 155 farms for detailed socio-economic surveys.

**Table 15**: Farm classification by levels in resource endowment in 5 Malian villages

| District | Villages | Farm number | Farm resource endowment groups (%) | | |
|---|---|---|---|---|---|
| | | | high | medium | low |
| San | Cinzara | 73 | 8 | 27 | 64 |
| | Toura-Marka | 39 | 5 | 26 | 69 |
| | Bobo-wéré | 26 | 27 | 8 | 65 |
| Ségou | Nyantia | 54 | 7 | 11 | 81 |
| | Sanogola | 62 | 13 | 11 | 76 |

Two benchmark sites representative of the semi-arid zone were selected in central Mali. Both sites encompass several villages (Table 1). The first benchmark site is located in the relatively densely populated vicinity of San in the wetter part of the semi-arid zone, on soils that include alluvial soils of the Bani river. This site is also the zone of intervention of an IFAD funded project (PDR) and of the Malian Cotton agency (CMDT). The second benchmark site is located in a drier zone close to Ségou, the second largest city in Mali. Soils are alluvial soils of the Niger river or luvisols on sandy deposits.

In all the villages of the two sites the main economic activities consist of crop and livestock production. The cropping system is based on two staple cereals: sorghum and millet with some maize and rice in low-lying areas. The cereals are often cropped in association with cowpea, groundnut, Bambara nut and some vegetables. Due to high population density and proximity of benchmark sites to towns, fallowing as a means of restoring soil fertility is less practiced than in the past. Furthermore, due to limited use of inorganic fertilizer and decreasing availability of rangeland, which also reduces animal manure availability, soil fertility is declining causing a decrease in yields. The most important livestock species is cattle and it serves multiple functions - traction, dairy and meat. Livestock contribute about 25% of total farm income and 16% of household consumption.

Group interviews in 5 Malian villages established thresholds specific to each village in land, labor and livestock assets between well, medium and poorly endowed farms (Table 16).

**Table 16**: Criteria given by the farmers in group interviews to define three farm types by resources endowment in 5 Malian villages.

| Farm assets | Farm types based on asset endowment | Cinzara | Toura-Marka | Bo-wéré | Sanogola | Nyantia |
|---|---|---|---|---|---|---|
| Crop land (ha) | high | >15 | >12 | >6 | >10 | >20 |
| | medium | 36294 | 36498 | 36315 | 36437 | 36299 |
| | low | <5 | <5 | <5 | <5 | <5 |
| Labour (man year) | high | >12 | >8 | >6 | >5 | >15 |
| | medium | 36498 | 36376 | 36312 | 36281 | 36294 |
| | low | <5 | <5 | <2 | <2 | <5 |
| Livestock (head) | high | >100 | >70 | >100 | >30 | >25 |
| | medium | 50-100 | 50-70 | 50-100 | 36309 | 36304 |
| | low | <50 | <50 | <50 | <5 | <5 |

There were indeed, large disparities between farms in access to resources and assets (table 17), but less so between villages within and across benchmark sites. In numbers poor households dominate other wealth categories at both benchmark sites (table 18).

**Table 17** Average resource endowments by class category in study villages in central Mali

| Benchmark site | Villages | Category | Labor (adult equiv.) | Land Area (ha) | Cattle (head) | Sheep (head) | Goats (head) | Nature of the development Project |
|---|---|---|---|---|---|---|---|---|
| Ségou | Kondogola | High | 7.0 | 20 | 23 | 4 | 14 | IFAD funded project FODESA (starting in 2000) |
| | | Medium | 6.0 | 12.5 | 5 | 4 | 4 | |
| | | Low | 6.3 | 3 | 3 | 3 | 3 | |
| | Sonogola | High | 8.1 | 10 | 4 | 4 | 6 | |
| | | Medium | 5.4 | 7.5 | 4 | 3 | 3 | |
| | | Low | 4.4 | 3 | 2 | 2 | 2 | |
| San | Cinzara | High | 9.3 | 15 | 37 | 8 | 5 | IFAD funded Programme for Diversification of revenues (PDR) |
| | | Medium | 6.3 | 10 | 7 | 5 | 4 | |
| | | Low | 5.6 | 3 | 1 | 2 | 2 | |
| | Toura-Marka | High | 12.0 | 12 | 56 | 52 | 3 | |
| | | Medium | 10.6 | 8.5 | 7 | 7 | 2 | |
| | | Low | 5.6 | 3 | 2 | 2 | 1 | |
| | Bobo-Wèré | High | 10.3 | 8 | 18 | 4 | 14 | |
| | | Medium | 8.8 | 5 | 3 | 3 | 2 | |
| | | Low | 4.3 | 3 | 2 | 2 | 8 | |

**Table 18.** Distribution of households by wealth categories (number of households surveyed).

| Wealth category | Benchmark sites | |
|---|---|---|
| | San | Ségou |
| High | 13.5 | 10.0 |
| Medium | 20.5 | 11.0 |
| Low | 66.0 | 79.0 |
| Total | 100.0 | 100.0 |

Due tight cropping calendar and the particularities of the alluvial soils animal traction is particularly important in the farming systems of central Mali. The average animal traction equipment owned by the different wealth groups is shown in Table 19.

**Table 19**. Average number of draft animals and animal traction equipment by class categories in benchmark sites in Mali

| Wealth category | Draft animals and animal drawn equipment | | | | | |
|---|---|---|---|---|---|---|
| | Draft oxen | | Plough | | Carts | |
| | San | Ségou | San | Ségou | San | Ségou |
| High | 5.12 | 3.57 | 2.12 | 1.43 | 1.46 | 1.29 |
| Medium | 2.50 | 3.33 | 1.44 | 1.44 | 1.01 | 1.11 |
| Low | 0.98 | 1.38 | 0.74 | 0.70 | 0.53 | 0.55 |

## 2.2. Technological options for more efficient crop-livestock integration

The focus of livestock production in central Mali is on cattle, with two main traded outputs fattened animals and dairy products. The proximity of the benchmark sites from the urban markets of San and Ségou makes dairy production particularly attractive. However, seasonal fluctuations in feed availability and quality affect the regularity of milk production if no adapted feed supplement is provided to the lactating cows. For cattle fattening and dairy production, farmers use an industrial by-product, ABH ( 'Aliment Betail Huicoma' derived from cotton processing), as a supplement. However, it is expensive and availability fluctuates. It was thus decided with farmers to test alternative and cheaper feed supplements. The heavy textured alluvial soils at the two benchmark sites justified testing a dual purpose sorghum breed, a 'sweet sorghum' (Malisor 92-1) as a potential feed to improve the performance of the dairy cows. The additional manure produced by the cows could, combined with locally available rock phosphate(Tilemsi), be returned to the soil cropped with sweet sorghum. Cropping sweet sorghum on soils fertilized with manure enriched with rock phosphate and produced by dairy cows fed sweet sorghum as supplement feed during the dry season was thus the integrated crop-soil management-livestock package tested in the two benchmark sites. In addition, cattle fattening with diets based on rice straws produced in villages close to the Niger or the Bani rivers, associated to locally produced supplements and small amounts of industrial supplements was tested in a village of the Ségou benchmark site. The excretions and feed refusal from the fattened cattle were collected and applied as manure on millet-cowpea cropped on soils which fertility is decreasing because of continuous cropping with no inputs.

## 2.3. Ex-ante economic impact assessment.

Manure enriched in rock phosphate applied to a sweet sorghum crop

Economic analysis conducted to assess, ex-ante, the profitability of soil fertilization on a sweet sorghum crop showed that the combination of 5 t ha$^{-1}$ of manure plus 300 kg ha$^{-1}$ of rock phosphate yielded a large positive marginal rate of return of + 263%, while the use of 5 t ha$^{-1}$ of manure alone only yielded + 108% rate of return (Table 20).

**Table 20**. Marginal analysis of sweet sorghum production in Mali.

| Technical and economic parameters expressed per ha | Type of soil amendment | | |
|---|---|---|---|
| | Control: No input | 5000 kg manure | 5000 kg manure + 300 rock phosphate |
| Grain yield (t $ha^{-1}$) | 0,60 | 0,80 | 1,20 |
| Straw yield (t $ha^{-1}$) | 1,80 | 2,40 | 3,60 |
| Grain sale price (CFA $kg^{-1}$) | *100,00* | *100,00* | *100,00* |
| Straw sale price (CFA $kg^{-1}$) | *3,00* | *3,00* | *3,00* |
| Gross value (CFA $ha^{-1}$) | 65 400,00 | 87 200,00 | 130 800,00 |
| Rock phosphate cost (CFA $ha^{-1}$) | 0,00 | 0,00 | 18 000,00 |
| Manure cost (CFA $ha^{-1}$) | 25 000,00 | 0,00 | 25 000,00 |
| Urea cost (CFA $ha^{-1}$) | 0,00 | 10 500,00 | 0,00 |
| DAP cost (CFA $ha^{-1}$) | 0,00 | 25 000,00 | 0,00 |
| Inputs cost (CFA $ha^{-1}$) | 25 000,00 | 35 500,00 | 43 000,00 |
| Labour cost (CFA $ha^{-1}$) | 32 000,00 | 32 000,00 | 32 000,00 |
| Total variable costs (CFA $ha^{-1}$) | 57 000,00 | 67 500,00 | 75 000,00 |
| Gross margin (CFA $ha^{-1}$) | 8 400,00 | 19 700,00 | 55 800,00 |
| Marginal rate of return (%) | na | 107,62 | 263,33 |

Use of sweet sorghum stover in the dry season feeding of dairy cows.
The cost benefit analysis indicated that the farmer practice was leading to a very poor gain of 27 CFA per cow and per day. Including sweet sorghum in the diet should increase the benefit to 44 CFA with 2kg of stalks and to 238 CFA with 4 kg per cow and per day. And thus, the marginal rate of return increases with the rate of sweet sorghum stover included in the diet (table 21).

**Tableau 21** : Marginal analysis of alternative diet given to dairy cows. All diet include ABH (Aliment Bétail Huicoma: a concentrate made of cotton cakes) and the improved diets include dry stovers of sweet sorghum while the farmer practice include instead dry straws that could be from other sorghum, millet of bush grass

| Parameters measured expressed per dairy cow and per day | Diet tested | | |
|---|---|---|---|
| | 3.5 kg ABH + 8 kg straws | 1,5 kg ABH + 2 kg sweet sorghum s | 1,5 kg ABH + 4 kg sweet sorghum |
| Cows per treatment | 20 | 23 | 20 |
| Milk yield (l $cow^{-1}d^{-1}$) | 1 | 1,5 | 2,5 |
| Milk sale price (CFA $l^{-1}$) | *200* | *200* | *200* |
| Manure yield (kg $cow^{-1}d^{-1}$) | 1,25 | 1,25 | 1,25 |
| Manure sale price (CFA $kg^{-1}$) | *5* | *5* | *5* |
| Cross value (CFA $cow^{-1}d^{-1}$) | 206,25 | 306,25 | 506,25 |
| Total input cost (CFA/group) | 53 077 | 238 520 | 167 110 |
| Milk extraction (days x cow) | 438 | 1 165 | 795 |
| Input cost (CFA $cow^{-1}d^{-1}$) | 121 | 205 | 210 |
| Labour cost (CFA $cow^{-1}d^{-1}$) | 16 | 16 | 16 |
| Veterinary care cost (CFA $cow^{-1}d^{-1}$) | 42 | 42 | 42 |
| Total variable costs (CFA $cow^{-1}d^{-1}$) | 179 | 263 | 268 |
| Gross margin (CFA $cow^{-1}d^{-1}$) | 27 | 44 | 238 |
| Marginal rate of return (%). | Na | 20 | 237 |

Improved diets to fatten culled oxen
The two diets proposed appears largely more profitable than farmer practice (table 22) with a difference of about 20 000 CFA. They did not differ significantly one from the other.

**Table 23**: Marginal analysis of alternative diets given to culled oxen for fattening. The diet include ABH (Aliment Bétail Huicoma: a concentrate made of cotton cakes) and MC (a commercial mineral complex)

| Parameters measured over the 3 months of the fattening period and expressed per ox | Diet tested in addition to 8 kg rice straws | | |
|---|---|---|---|
| | 3 kg ABH + 2 kg bran | 3 kg ABH + 1.5 kg Molasses + 20 g MC | 2 kg ABH + 2 kg Molasses 65 g urea + 20 g MC |
| Number of cattle fattened | 6 | 7 | 7 |
| Weight gain (Kg /ox /3months) | 20 | 54 | 54 |
| Final weight final (kg/oxl) | 240 | 275 | 275 |
| Cattle sale price (CFA $kg^{-1}$) | 500 | 500 | 500 |
| Manure (kg/ox/3months) | 360 | 360 | 360 |
| Manure sale price (CFA $kg^{-1}$) | 5 | 5 | 5 |
| Gross product (CFA/ox /3months) | 121 800 | 139 300 | 139 300 |
| Total cost of inputs (CFA/3month) | 127 500 | 245 730 | 254 367 |
| Input costs (CFA/ox /3months) | 21 250 | 35 104 | 36 338 |
| Veterinary care (CFA/ox /3months) | 3 000 | 3 000 | 3 000 |
| Labour (CFA/ox /3months) | 1 500 | 1 500 | 1 500 |
| Total variable cost (CFA/ox /3months) | 25 750 | 39 604 | 40 838 |
| Cattle purchase price (CFA/ox) (1) | 60 000 | 60 000 | 60 000 |
| Cattle purchase price (CFA/ox) (2) | 80 000 | 80 000 | 80 000 |
| Net benefit (CFA/ox /3months)(1) | 36 050 | 39 696 | 38 462 |
| Net benefit (CFA/ox /3months) (2) | 16 050 | 19 696 | 18 462 |
| Marginal rate of return (%) (1) | na | 26 | 16 |

## 2.4 Project implementation, trials and results

Sweet sorghum at San and Ségou benchmark sites
Following a preliminary screening trial in 1998 to select among dual purpose cultivars of sorghum a fertilizer trial has been carried out during 1999 wet season in the field of 16 farmers from three villages chosen in the area of intervention of the IFAD funded project in San district and in two villages of Ségou district. The trial consisted in comparing the yields of a dual purpose sweet sorghum (Malisor 92-1) cropped on two half-an-hectare plots that had received 5 t ha $^{-1}$of manure associated in one of the plot to 300 kg ha$^{-1}$ of local rock phosphate (Tilemsi). The sceening trial conducted in 1998 identified two sweet sorghum cultivars that yielded 1330 and 1428 kg grain ha $^{-1}$ respectively and which stover contained 0.76 Feed Unit kg $^{-1}$ DM and 20 g Digestible Protein per kg DM.. The identified sweet sorghum (Malisor 92-1) was successful cropped by 14 of the 16 farmers (2 were flooded during 1999 heavy rains).

In 2000, a the similar fertilizer trial was carried out in the field of 34 farmers from three villages in the San district and in eight villages of Ségou district. The trial consisted of comparing the yields of a single cultivar of dual purpose sweet sorghum (Malisor 92-1) cropped on two 0.5 hectare plots that had received the same amount of manure, 5 t ha $^{-1}$, combined in one of the plot with 150 kg ha$^{-1}$ of local rock phosphate, and in two of the Ségou villages with 100 kg ha $^{-1}$ of di-ammonium phosphate plus 50 kg ha $^{-1}$ urea. Unfortunately, the farmers did not harvest grains separately on the two plots. Thus, only total yield and treatment effect on the feed quality of the stovers were measured. Because of late planting and poorly distributed rains, fodder yields of the dual purpose sweet sorghum (Malisor 92-1) were extremely variable ranging from 290 to 6240 kg DM ha $^{-1}$with an average of 1730 ± 1347 kg DM ha $^{-1}$. Average N content in the stovers was significantly higher in plots that received di-ammonium phosphate and urea in addition to compost (1.00 ±0.24%) than in all other treatments (control with no input: 0.77 ±0.20%; compost 0.68 ±0.16%; compost with rock phosphate 0.79±0.21%).

In 2001, the trial on sweet sorghum crop was carried out in the field of 34 farmers from three villages in the San district and in seven villages of Ségou district with a minimum of two farmers per village. Voluntary farmers had to manage fields in low lands suitable to crop sorghum and breed some dairy cattle. The trial consisted of comparing the yields of a dual purpose sweet sorghum (Malisor 92-1) cropped on three 0.5 hectare plots that had received the same amount of manure, 5 t ha $^{-1}$, either alone (Farmer practice control plot) or combined with 300 kg ha $^{-1}$ of local rock phosphate (Tilemsi), or else with 100 kg ha $^{-1}$ of di-ammonium phosphate (DAP) plus 50 kg ha $^{-1}$ urea. Unfortunately, the farmers did not harvest grains separately on the two plots. Thus, only total yield and treatment effect on the feed quality of the stovers were measured. Soil samples collected before the onset of the trial and at the harvest in 1999 and 2000 were analyzed for chemical composition as well as samples of sweet sorghum stovers. Better rain distribution in 2001 resulted in much higher and homogeneous yields than in 2000 for which stover yields were extremely variable ranging from 290 to 6240 kg DM ha$^{-1}$with an average of 1730 ± 1347 kg DM ha$^{-1}$. Grain and stover yields increased with the with the addition of combined DAP and urea, and even more with addition of Tilemsi rock phosphate (table 24).

**Table 24**: Mean grain and stover yields of sweet sorghum (Malisor 92-1) in 34 farms of San and Ségou districts in 2001

| Yields (t ha$^{-1}$) | Control (5t manure ha$^{-1}$) | 5t manure + 100kg DAP + 50 kg Urea ha$^{-1}$ | 5t manure ha$^{-1}$ + 300 kg rock P ha$^{-1}$ |
|---|---|---|---|
| Grain yield | 1,26 | 1,35 | 1,55 |
| Stover yield | 2,51(1,37) | 2,70 (1,62) | 3,10 (1,97) |

- () in brackets standart deviation of the mean

None of the soil changes recorded following manure or manure and rock phosphate applications were significant because of the small number of samples relative to micro-heterogeneity (table 25) However, trends were as follows when comparing samples collected at the onset with samples collected after the first harvest in 1999. Top soil pH increased from 4.63 to 4.73 and 4.86 respectively following application of 5t manure alone or with 150 kg ha$^{-1}$ rock phosphate (table 25). Organic carbon only increased from 0.27 to 0.32 % with manure application. Soluble phosphorus increased from 3.83 to 7.51 with manure and to 9.27 ppm kg$^{-1}$ with manure and rock phosphate. This could be explained by the phosphorus content of manure, close to 0.2% of which 75% could be used by plants and 60% should available during the first year and Tilemsi rock phosphate contains 30% $P_2O_5$ and thus 13% P which solubility should be enhanced by the acidity of the soil. Soluble potassium also increased with the amendments from 14.15 to 14.76 with manure and 15.75 ppm kg$^{-1}$ with manure and rock phosphate. This small increase could be explained by the K content of manure estimated at 1,3 %.

**Table 25:** Soil pH, and concentrations in Organic carbon , total N, soluble P and K in samples collected at the onset of the experiment or at first harvest following application of 5t DM $ha^{-1}$ manure alone or with 150 kg $ha^{-1}$ Tilemsi rock phosphate (October 1999) in Ségou and San.

| Treatments | PH | Organic C % | Total N % | Soluble P ppm $kg^{-1}$ | Soluble K ppm $kg^{-1}$ |
|---|---|---|---|---|---|
| Trial onset | 4.63 | 0.27 | 0.03 | 3.83 | 14.15 |
| 5t manure | 4.73 | 0.32 | 0.03 | 7.51 | 14.76 |
| 5t manure + 150 kg RP | 4.86 | 0.31 | 0.04 | 9.27 | 15.73 |
| Mean | 4.74 | 0.30 | 0.03 | 6.87 | 14.88 |
| CV% | 10.0 | 45.5 | 28.5 | 101.9 | 36.8 |
| Significance | NS | NS | NS | NS | NS |

Analysis performed on soil sampled in 2000 confirmed these results: none of the differences between treatments were significant (table 26) and there were trends towards pH, soluble P and K increase with manure application.

**Table 26**: Soil pH, and concentrations in Organic carbon , total N, soluble P and K in samples collected at the onset of the experiment or at harvest following application of 5t DM $ha^{-1}$ manure alone or with 150 kg $ha^{-1}$ Tilemsi rock phosphate (October 2000) in Ségou and San

| Treatments | PH | Organic C % | Total N % | Soluble P ppm $kg^{-1}$ | Soluble K ppm $kg^{-1}$ |
|---|---|---|---|---|---|
| Trial onset | 4.59 | 0.39 | 0.04 | 3.93 | 14.64 |
| 5t manure | 4.88 | 0.38 | 0.04 | 4.75 | 18.07 |
| 5t manure + 150 kg RP | 4.65 | 0.30 | 0.03 | 4.72 | 17.00 |
| Mean | 4.71 | 0.35 | 0.04 | 4.47 | 16.57 |
| CV% | 5.7 | 33.3 | 26.0 | 44.0 | 30.2 |
| Significance | NS | NS | NS | NS | NS |

The combined application of manure with rock phosphate did not led to further increases of pH, nor soluble P and K contents. And contrary to results in 1999, manure, with or without rock phosphate did not increased organic carbon nor total nitrogen contents.

Dairy cows supplemented with sweet sorghum

In 2000, the use of sweet sorghum to feed dairy cows in a peri-urban area of Segou was tested on 24 cows owned by 10 of the farmers who participated in the sweet sorghum crop trial. All cows had access to grazing land, mineral licks (CMV) and received one of three different supplements: 1 to 3 kg ABH plus 1 to 2 kg rice bran (control), or 1.5 kg ABH plus 2 kg sweet sorghum stover, or 1.5 kg ABH plus 4 kg of sweet sorghum. The cows and their calves were fed and monitored from January to June 2000. Supplementation of dairy cows with 2kg of sweet sorghum stover resulted in a decrease of total feed intake (2.65±0.61 kg DM daily instead of 3.12±0.09), while it increased to 3.4 ± 1.04 kg with 4 kg of sweet sorghum. Milk production did not differ significantly with the feed treatments (2.3 ±0.65 kg for the control, 2.2±0.83 kg and 2.1±0.70 kg for 2 and 4 kg of sweet sorghum respectively), nor the weight changes of cows and calves. Cows lost on average -411±280, -331±468 and -333±124 g $d^{-1}$ live weight while calves gained 49±221, 274±237 and 279±260 g $d^{-1}$.

In 2001, the use of sweet sorghum to feed dairy cows was tested in four villages of the peri-urban area of Ségou and two villages in the disctrict of San. The trial was conducted on a total of 63 grazing dairy cows fed three type of supplement diet within each village (table 27).

**Table 27**: Distribution of dairy cows per diet treatment, village and sites in the supplementation trial conducted in 2001

| Site | Village | Control diet | Diet 3kg SS | Diet 5kg SS |
|---|---|---|---|---|
| Ségou | Bakawéré | 3 | 2 | 2 |
| | Dakala | 3 | 4 | 4 |
| | M'pènèbougou | 5 | 5 | 5 |
| | Niathia | 5 | 5 | 2 |
| San | Cinzara | 2 | 4 | 4 |
| | Yorobougou | 2 | 3 | 3 |
| All sites | | 20 | 23 | 20 |

All cows had access to grazing land and received either 1 to 3 kg ABH plus 1.5 kg millet bran and ad libitum landrace sorghum stover in the farmer's practice control, or only 2 kg ABH and 20 gr of salt plus either 3 kg or 5kg sweet sorghum and stover (table 28). The objective of the study was to test fattening diets that were cheaper than what farmers are currently using. Indeed, the current farmer practice relies heavily on ABH which is relatively expensive. The two alternative diets were calculated to cover 2/3 of the requirements of a 300 kg cow which produces 3 liters of milk per day.

**Table 28**: Composition of the three diet tested on grazing dairy cows (kg $d^{-1}$ per cow) including ABH (Aliment bétail Huicoma) which is a concentrate based on cotton cakes. Ségou and San, 2001.

| Diet composition kg $d^{-1}$ | Sweet sorghum stover | Other sorghum stover | ABH | Millet Bran | Salt |
|---|---|---|---|---|---|
| Control diet | - | 3 | 1 à 3 | 1,5 | - |
| Diet 3kg SS | 3 | - | 2 | - | 0.02 |
| Diet 5kg SS | 5 | - | 2 | - | 0.02 |

NB : In the village of Niantia, cows of the control lot are only fed landrace sorghum stovers and millet bran

**Table 29:** Mean intake per cow and per day measured per village for the three supplement diets tested in the sites of Ségou and San (kg fresh weight $d^{-1}$)

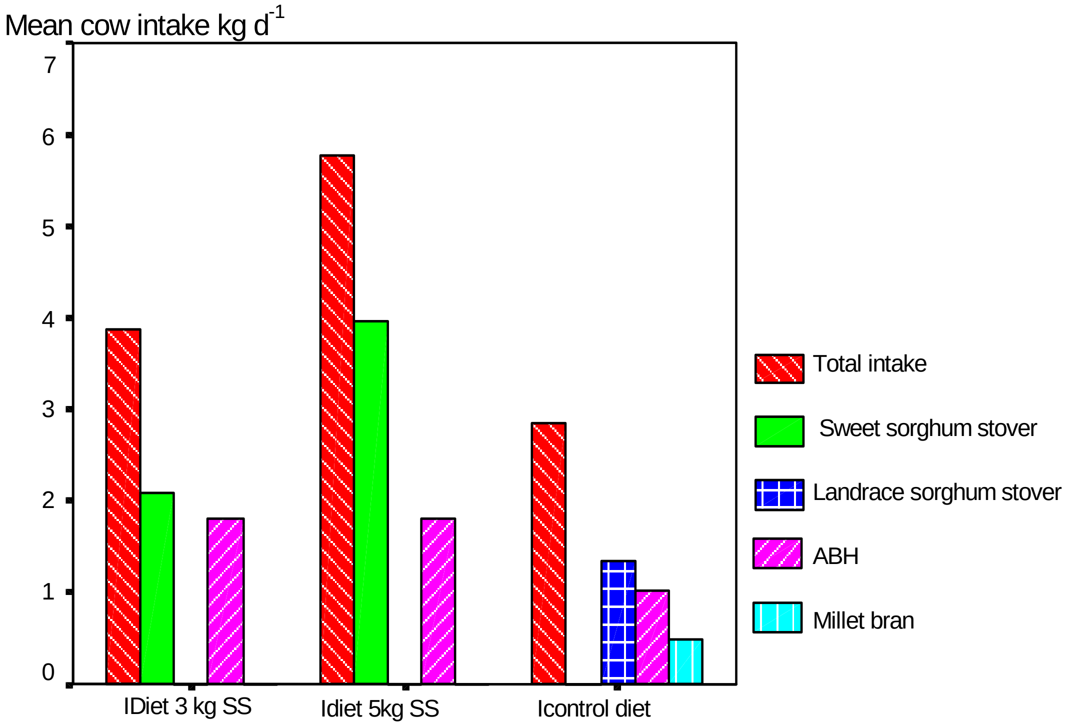
| Diets | Diet 3 kg SS | | | Diet 5kg SS | | | Control diet | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Villages | Ssorg | ABH | Total | Ssorg | ABH | Total | Lsorg | ABH | Millet bran | Total |
| Bakawéré | 1.28 | 1.97 | 3.25 | 3.91 | 1.97 | 5.87 | - | 1.50 | - | 1.50 |
| Dakala | 2.80 | 2.00 | 4.80 | 4.26 | 2.00 | 6.26 | - | - | - | - |
| Mpénébougou | 2.41 | 1.80 | 4.21 | 4.13 | 1.56 | 5.70 | - | - | - | - |
| Niantia | 1.95 | 1.51 | 3.46 | 2.95 | 2.00 | 4.77 | 2.20 | 0.32 | 0.78 | 3.30 |
| Cinzara | 1.69 | 1.80 | 3.49 | 3.69 | 1.80 | 5.49 | - | 2.00 | - | 2.00 |
| Yorobougou | 1.95 | 1.84 | 3.75 | 3.80 | 1.79 | 5.59 | - | 2.50 | - | 2.50 |

Ssorg = Sweet Sorghum; Lsorg = Landrace sorghum

.

Parameters measured included cow intake in sorghum stover, quantity of milk milked, animal growth (through monthly body measures of cows and weekly weight of cows), body condition was coded as by Cissé 1995 (6 classes). In all sites sweet sorghum was well accepted, and access to sweet sorghum increased the intake of supplement feed from 1.5 – 3 kg $d^{-1}$ to 3 - 6 kg $d^{-1}$ (Table 29). All ABH distributed was eaten whatever it was associated with (Fig 1).

**Figure 1** Mean daily intake of supplement feed by grazing cows offered three different diets in Ségou and San, March to July 2001



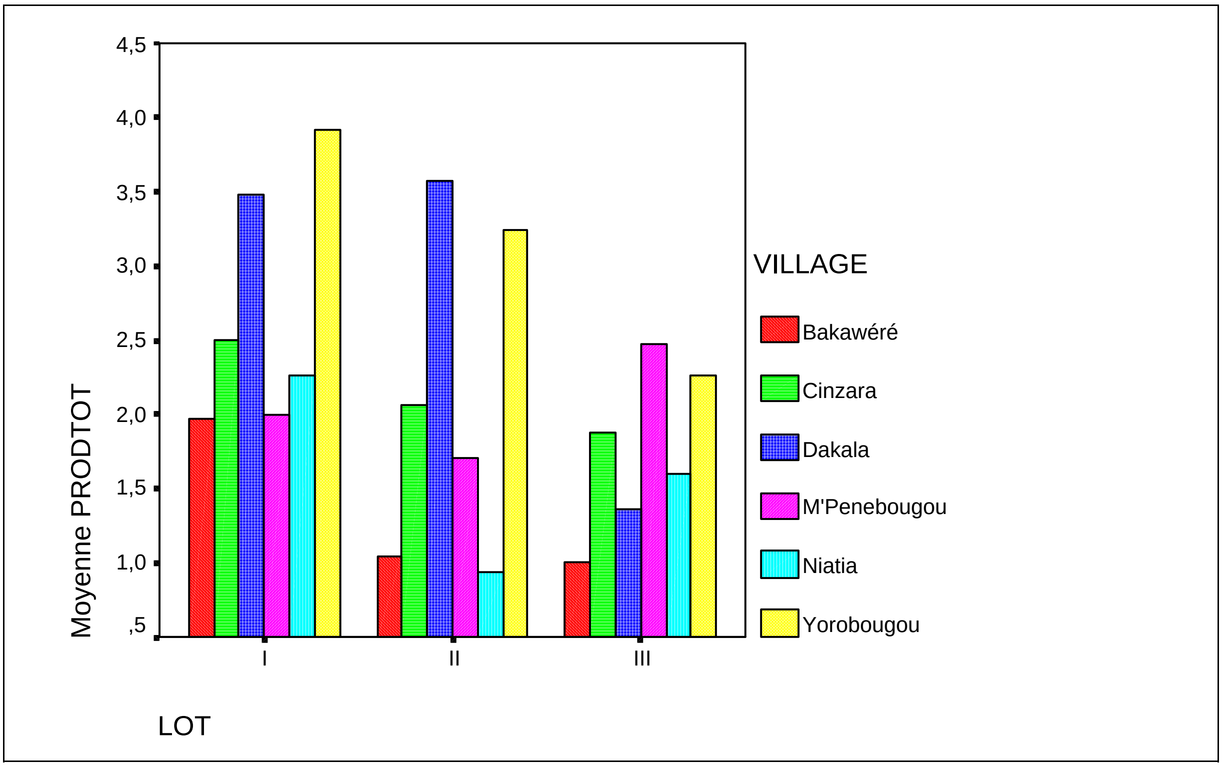

Across sites and farms the production of extracted milk was superior (P = 0.01) with the diets including sweet sorghum(table 31) However, in M'Pénébougou, one of the village of the peri-urban zone of Ségou, the milk production of the control and the diet including 3kg of sweet sorghum were similar and superior to the milk production of the cow supplemented with 5 kg of sweet sorghum. Moreover, in the village of Bakawéré and Niatia the 5kg Sweet Sorghum diet resulted in less extracted milk than the 3 kg and the control diet. In Dakala (Ségou) as well as in Cinzara and Yorobougou (San), there were no differences between the two diets including sweet sorghum which matches with higher milk yield than in the control (Figure 2)

**Table 31** Mean milk yield per cow( kg $d^{-1}$), per type of diet supplementation and per village.

| Villages | Supplement diet treatments | | |
|---|---|---|---|
| | Diet 3 kg SS | Diet 5 kg SS | Control diet |
| Bakawéré | 1,98 b | 1,04 a | 1,00 A |
| Cinzara | 2,50 a | 2,06 Ab | 1,87 B |
| Dakala | 3,48 a | 3,57 A | 1,36 B |
| M’Pénébougou | 1,99 ab | 1,70 A | 2,47 B |
| Niantia | 2,26 a | 0,93 B | 1,60 Ab |
| Yorobougou | 3,92 b | 3,24 B | 2,27 A |

Yields followed by the same letter were not different at P = 0.05

**Figure 2**: Mean daily milk yield per cow (kg d$^{-1}$) for each supplement treatment (I = diet 3kg SS, II = 5kg SS III = control diet ).

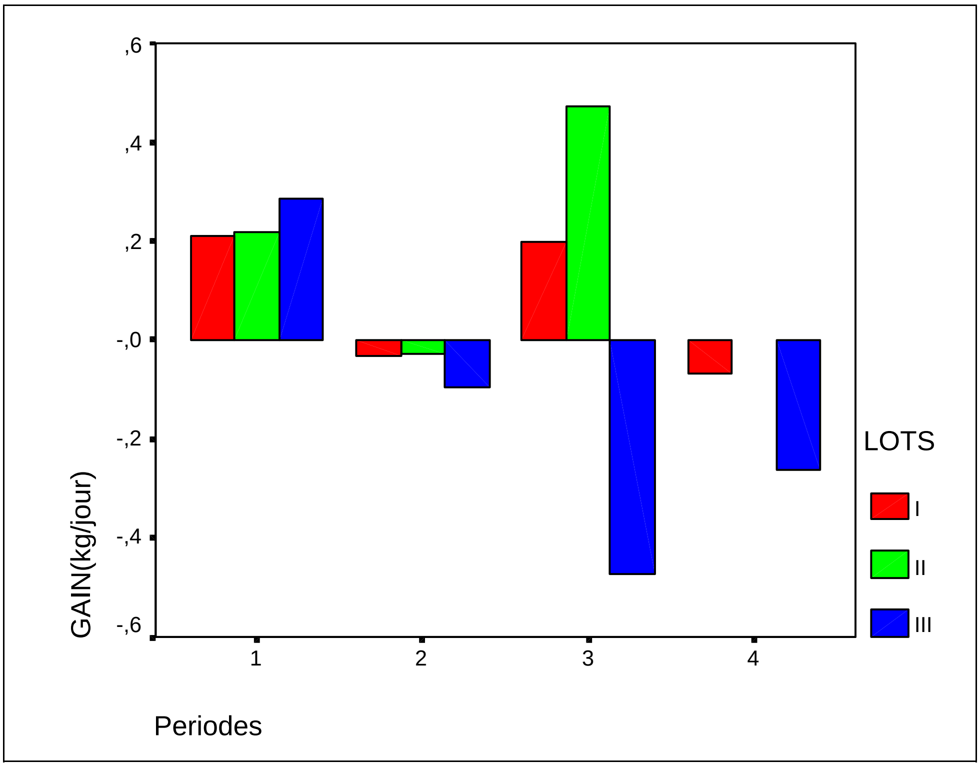



The analyses of the variance of mean daily weight gains indicate no significant effect of the supplement diets across villages (P=0.87) nor within villages (P=0.97). Cow weights were positive in March, negative in April and more so for the cows fed the control diet (table 32). In May the cows offered sweet sorghum had gained some weight while the control ones kept loosing weight, especially in the village of Bakawéré (Figure 3). More over most of the cow supplemented with sweet sorghum returned in heat and get covered before the end of the dry.

**Table 32** : Mean daily weight gain of cows (kg d$^{-1}$) per month (March, April, May) for each supplement treatment and village

| Sites | Diet 3 kg SS | | | | Diet 5 kg SS | | | | Control diet | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | Mean | P1 | P2 | P3 | Mean | P1 | P2 | P3 | Mean |
| Bakawèrè | 0.35 | 0.20 | 0.2 | 0.25 | 0.13 | 0.36 | 0.47 | 0.32 | 0.66 | 0.12 | -0.47 | 0.1 |
| Dakala | 0.56 | 0.00 | - | 0.28 | 0.56 | 0.00 | - | 0.28 | 0.40 | 0.00 | - | 0.2 |
| Mpenebougou | 0.00 | 0.00 | - | 0.00 | 0.06 | -0.06 | - | 0.00 | 0.10 | -0.25 | - | -0.03 |
| Niantia | 0.14 | 0.08 | - | 0.11 | 0.82 | - | - | 0.82 | -0.37 | 0.88 | - | 0.25 |
| Cinzara | 0.32 | -0.11 | - | 0.10 | 0.02 | -0.03 | - | 0.00 | 0.50 | -0.44 | - | 0.03 |
| Yorobougou | -0.01 | -0.19 | - | -0.10 | 0.16 | -0.26 | - | -0.05 | 0.31 | -0.44 | - | -0.06 |
| Mean | 0.22 | -0.00 | 0.2 | 0.11 | 0.29 | -0.00 | 0.47 | 0.23 | 0.26 | -0.06 | -0.47 | 0.08 |

**Figure 3**: Mean daily weight gain of cows (kg d-1) for each supplement treatment (I = diet 3kg SS, II = 5kg SS III = control diet ) from March to June 2001 in Ségou and San.



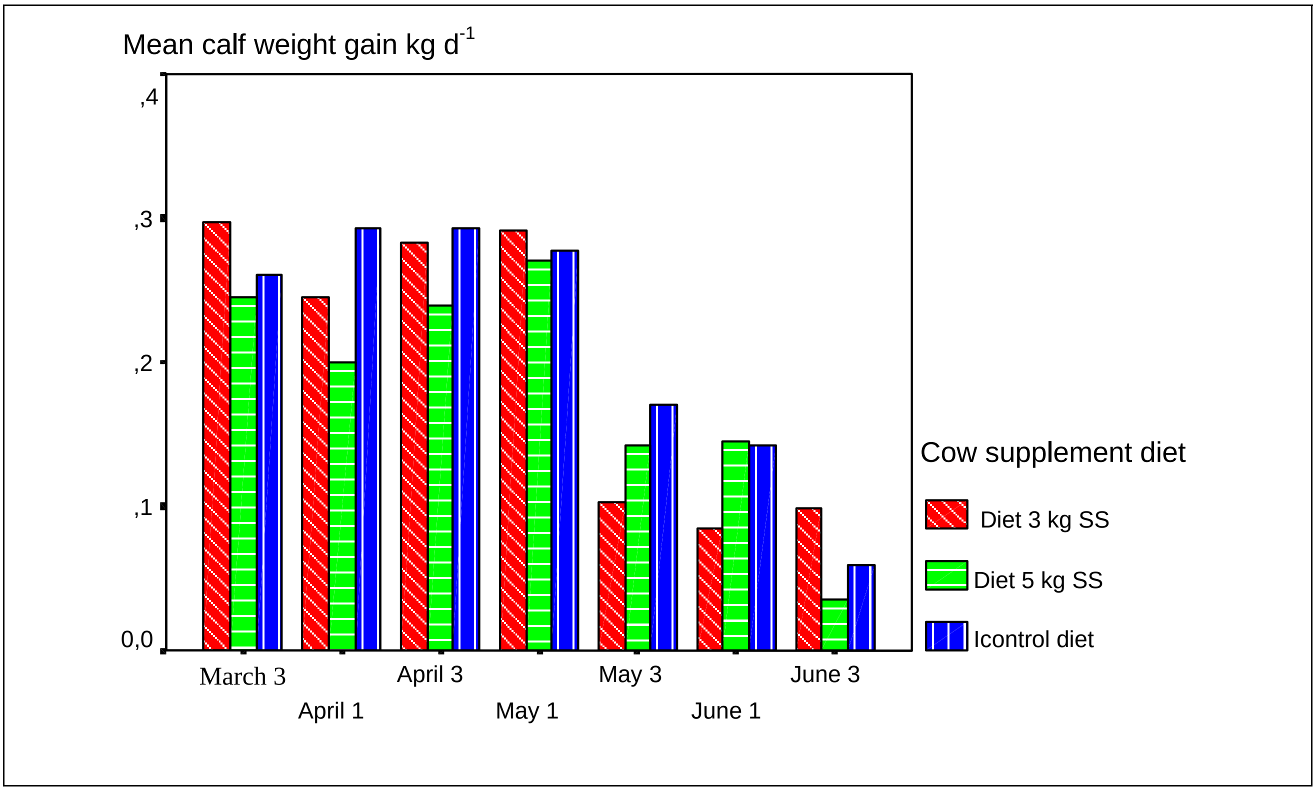

There were no effect of the supplement diets on the weight gain of the calves, across village (P=0.48) and within village except for the village of Cinzara where the control had lower gain than the calves of supplemented cows (table 19). L'analyse du graphique par période indique que pendant les 4 premières périodes les gains des trois lots se comportent de la même manière ; les 3 dernières périodes sont aussi semblables (Figure 4).

**Table 34** Mean daily weight gains of calves per village and per type of supplement feed offered to the mother (kg $d^{-1}$)

| Village | Calves daily weight gain (kg $d^{-1}$) | | |
|---|---|---|---|
| | Diet 3 kg SS | Diet kg SS | Control diet |
| Bakawéré | 0,23 | 0,16 | 0,19 |
| Cinzara | 0,20 a | 0,28 a | 0,17 b |
| Dakala | 0,22 | 0,11 | 0,37 |
| M'Pénébougou | 0,32 | 0,24 | 0,18 |
| Niantia | 0,18 | 0,09 | 0,35 |
| Yorobougou | 0,18 | 0,30 | 0,35 |

The weight gains followed by the same letter were not significantly different at P= 0.05.

**Figure 4**: Mean daily weight gain of calves (k $d^{-1}$) per supplement treatment of the mother and from March to June 2001. Sites of Ségou and San.




At the trial onset the average condition score was not different between the three treatment cows (P= 0.48) and all cows were classified as 'lean'. At the end of the trial most of the cows offered the control diet had lost condition, while the cows offered sweet sorghum diets had maintained or improved condition, although the difference is not statistically significant ( Table 35)

**Table 35:** Changes of mean condition scores (1 to 5) of cows depending on supplement diet

| Supplement Diet treatments | Mean condition score of cows | | |
|---|---|---|---|
| | March | April | May |
| Diet 3 kg SS | 2.15± 0.14 | 2.30± 0.11 | 2.48± 0.16 |
| Diet 5 kg SS | 2.23± 0.14 | 2.25± 0.11 | 2.49± 0.15 |
| Control diet | 2.35± 0.19 | 2.45± 0.15 | 2.20± 0.21 |

Cattle fattening

In 2000, a cattle fattening trial was conducted in the millet-based agricultural system in the San area involving 20, 4 to 5 year old bulls owned by 9 farmers. The animals were fattened for 30 to 45 days. The objective of the study was to test fattening diets that were different from what farmers are currently using. Indeed, the current farmer practice relies heavily on ABH and is relatively expensive. The control diet included 3 to 4 kg ABH $d^{-1}$, and 1 to 2.5 kg $d^{-1}$ of millet bran. Two alternative diets were tested, the first included 3 kg of ABH, 1.5 of molasses, and 20g of mineral mix; the second included 2 kg of ABH, 2kg of molasses, 65 g of urea and 20 g of mineral mix. The test of alternative diets for bull fattening was not conclusive. Average daily weight gains with the alternative diets were inferior to those of the control animals (532±302 and 742±663 g $d^{-1}$, versus 857±510 g $d^{-1}$ for the control) but differences were not significant nor were significant differences in fecal output. Due to the inappropriate choice of control treatments and the inconclusive results reported above, it was not possible to conduct any meaningful economic analysis of the feeding trials. The design of the trial was revised in 2001 and implemented at the Ségou benchmark site.

In 2001, a cattle fattening trial was conducted for three months in a village of the peri-urban zone of Ségou, Kondogola, were 6 voluntary farmers tested one of two diets that had proved their efficiency in on-station trials (Table 36). A total of 20 animals were fattened, they include mostly males between 4 and 5 years of age but also old females and males. These animals were grouped into three weight classes, and animals were randomly alloted to the three treatments within each group. All animals were vaccinated against anthrax and pasteurellosis and treated against fascioliasis and intestinal parasites.

**Table 36**: Cattle fattening diet composition (kg $d^{-1}$ $animal^{-1}$)

| Fattening diet | Number of steers | Bush hay | ABH | millet bran | Molasses | Urea | Salt lick (CMV) |
|---|---|---|---|---|---|---|---|
| 'Molasses' | 7 | ad libitum | 3 | - | 1,5 | - | ad libitum |
| 'Urea' | 7 | ad libitum | 2 | - | 2 | 0.065 | ad libitum |
| 'Control' | 6 | ad libitum | 2 - 4 | 1 | - | - | - |

Feed intake was measure, as well as monthly weight changes, body condition was scored monthly (method by Cissé, 1995) on five classes (very lean, lean, fair, fat, very fat). Price of the animals at purchase and final sale were recorded. Feed intake of fattened animals was similar across diet (Table 37). However, the quantities of ABH concentrate varied largely in the control group

**Table 37**: Mean feed intake per cattle (kg $d^{-1}$) for each fattening diet, Kondogola, 2001.

| Diets | 'Molasses' | 'Urea' | 'Control' |
|---|---|---|---|
| Bush hay | 4.1±1.38 | 4.9±1.39 | 4.1±1.38 |
| Molasses | 1.2 | 1.6 | - |
| Millet bran | - | - | 0.9 |
| Urea | - | 0.065 | - |
| Salt lick Cmv | 0.05 | 0.05 | - |
| ABH | 2.76 | 1.84 | 2.62±1.44 |
| Total intake | 8.11 | 8.45 | 7.62 |

Mean weight gain did not differ between the two tested diets (at P = 0.05) but where both markedly superior to the control diet which gave poor weight gains (table 3). The performance of the tested diets were slightly inferior to last year ones and close to the on-station performance measured by Traoré et al., (1971): 500 to 600 g $d^{-1}$ and by Ouologuem *et al*. (2000): 443 to 789 g $d^{-1}$. The manure produced in the each of the three treatments were similar (table 38). With daily production of 8 to 11 kg twenty cattle in three month should produce enough manure to amend three hectares at 5t $ha^{-1}$

**Table 38:** mean daily weight gain and manure production per cattle depending on the fattening diet.

| Fattening diets | Mean daily weight gain (kg $d^{-1}$) | | | | Manure (kg $d^{-1}$) |
|---|---|---|---|---|---|
| | month 1 | month 2 | month 3 | mean 1-3 | |
| 'Molasses' | 0.88 | 0.55 | 0.12a | 0,518 a | 10.8 |
| 'Urea' | 0.63 | 0.41 | 0.37a | 0,470a | 11.2 |
| 'Control diet' | 0.60 | 0.13 | -0.47b | 0.08 b | 8.4 |
| Significance | ns | ns | s | ns | na |
| Probability | 0.25 | 0.41 | 0.003 | 0,006 | na |

At the onset of the trial the body condition of the animals was variable between very lean and lean in all groups. At the end of the trial animals were lean to lean-fair (2-2.5) in the control and between fair and fair-fat with tested diets (table 39). However, none of these differences were significant .

**Table 39**: Mean condition scores of the cattle at the on-set of the fattening trial and every month after for each diet treatment, Kondogola, 2001.

| Diets | Trial on-set | month 1 | month 2 | month 3 | mean |
|---|---|---|---|---|---|
| 'Molasses' | 1,75 | 2,62 | 2,75 | 3,0 | 2,53 |
| 'Urea' | 1,66 | 2,66 | 3,08 | 3,41 | 2,71 |
| 'Control' | 1,55 | 2,5 | 2,5 | 2,5 | 2,25 |
| Signification | ns | ns | ns | ns | ns |
| probability | 0,93 | 0,96 | 0,43 | 0,16 | 0,68 |

Sheep and goats fattening

Using a browse fodder bank to supplement sheep and goats fattened during the dry season was tested in 1999 at the benchmark site of Niono, within the irrigated scheme of 'Office du Niger'. The trial was discontinued in 2000 and the benchmark site abandoned as it had not been subject to a full survey, and that small ruminant was a minor component of this specific farming system. Never the less in 1999 a feed supplement trial has been conducted on 36 male sheep fattened for the market of the muslim celebration of Tabaski. The trial lasted 36 days and consisted in feeding Leucaena leucocephala fresh leaves as partial substitution (50% and 75%) for ABH (Aliment Bétail Huicoma), on industrial by-product based on cotton cake often used to supplement livestock in the Mali. Sheep intake of Leucaena leaves, partially substituted to the industrial feed supplement ABH, were 81 and 88 g kg $^{-0.75}$ d $^{-1}$ for subtitution rates of 50 and 75%, and average daily gains were 121 and 97 g d $^{-1}$ respectivelly compared to 75 g d $^{-1}$ for the control only fed ABH. Although these differences were not statistically significant they gave a clear indication of the potential of Leucaena to supplement livestock at lower cost.

## 2.5. Discussion and ex-post economic assessment

Manure, rock phosphate and sweet sorghum

The ex-post economic assessment of alternative soil amendments to grow sweet sorghum indicates that all three soil amendments options were profitable to the farmer (table 40). However, applying 5t ha$^{-1}$of manure enriched with 300 kg ha$^{-1}$ of rock phosphate gave the highest rate of return relative to the manure only amendment that is farmer's practice. The rate of return of the inorganic fertilizer trial was negative. The benefits and marginal rate of returns are much lower than calculated ex-ante, (table 20), however differences between treatments are oriented the same.

**Table 40:** Ex-post economic assessment of the soil amendment options to crop sweet sorghum (Ségou and San, 2000)

| | Soil amendment technologies tested | | |
|---|---|---|---|
| | Control manure | Inorganic fertiliser | Manure and fertilizer |
| Grain yield (t ha$^{-1}$) | 1,26 | 1,35 | 1,55 |
| Straw yield (t ha$^{-1}$) | 2,51 | 2,70 | 3,10 |
| Grain sale price (CFA kg$^{-1}$) | 100 000 | 100 000 | 100 000 |
| Straw sale price (CFA kg$^{-1}$) | 3 000 | 3 000 | 3 000 |
| Gross value (CFA ha$^{-1}$) | 133 030 | 143 100 | 164 300 |
| Rock phosphate cost (CFA ha$^{-1}$) | 0,00 | 0 | 18 000 |
| Manure cost (CFA ha$^{-1}$) | 25 000 | 0 | 25 000 |
| Urea cost (CFA ha$^{-1}$) | 0 | 10 500 | 0 |
| DAP cost (CFA ha$^{-1}$) | 0 | 25 000 | 0 |
| Inputs cost (CFA ha$^{-1}$) | 25 000 | 35 500 | 43 000 |
| Labour cost (CFA ha$^{-1}$) | 32 000 | 32 000 | 32 000 |
| Total variable costs (CFA ha$^{-1}$) | 57 000 | 67 500 | 75 000 |
| Gross margin (CFA ha$^{-1}$) | 76 030 | 75 600 | 89 300 |
| Marginal rate of return (%) | na | -4.10 | 73.72 |

Feed supplementation of dairy cows with sweet sorghum

The ex-post economic assessment of the use of sweet sorghum stovers in the diet of dairy cows indicates that all diets allow a gross margin of 200 to 280 CFA per cow and per day (table 41). The highest marginal return was reached with the diet composed of 3 kg of sweet sorghum stover and 2 kg of ABH concentrates, plus BKN salt lick. Adding further 2 kg of sweet sorghum did not increased milk yield and thus led a reduction of the marginal rate of return opposite to waht was excpected ex-ante (table 21).

**Table 41**: Ex-post economic assessment of three diet options to fed dairy cows (Ségou –San, 2000)

| Parameters measured expressed per dairy cow and per day | 3.5 kg ABH + 8 kg straws | 1,5 kg ABH + 2 kg sweet sorghum s | 1,5 kg ABH + 4 kg sweet sorghum |
|---|---|---|---|
| Cows per treatment | 20 | 23 | 20 |
| Milk yield (l cow$^{-1}$d$^{-1}$) | 1,71 | 2,64 | 2,35 |
| Milk sale price (CFA l$^{-1}$) | 200 | 200 | 200 |
| Manure yield (kg cow$^{-1}$d$^{-1}$) | 1,25 | 1,25 | 1,25 |
| Manure sale price (CFA kg$^{-1}$) | 5 | 5 | 5 |
| Cross value (CFA cow$^{-1}$d$^{-1}$) | 348,25 | 534,25 | 476,25 |
| Total input cost (CFA/group) | 53 077 | 238 520 | 167 110 |
| Milk extraction (days x cow) | 438 | 1 165 | 795 |
| Input cost (CFA cow$^{-1}$d$^{-1}$) | 121 | 205 | 210 |
| Labour cost (CFA cow$^{-1}$d$^{-1}$) | 16 | 16 | 16 |
| Veterinary care cost (CFA cow$^{-1}$d$^{-1}$) | 42 | 42 | 42 |
| Total variable costs (CFA cow$^{-1}$d$^{-1}$) | 179 | 263 | 268 |
| Gross margin (CFA cow$^{-1}$d$^{-1}$) | 169 | 272 | 208 |
| Marginal rate of return (%). | Na | 123 | 44 |

Cattle fattening

The ex-post economic assessment indicates that all three diets were beneficial. However the net benefit is very sensitive to the purchase price of the animal, and much better when this price is 60,000 CFA than higher such as 100,000 CFA. The rate of return was highest for the diet based on 3 kg ABH and salt lick, while unlike in the ex-ante assessment (table 22) the diet had a negative rate of return relative to the farmer practice (table 42).

## 2.6. Pathways for diffusion and adoption

Locally, the pathways for diffusion and adoption of tested technologies include discussions and participatory evaluation of the on-farm trials with farmers, technicians and extension agents of the development agencies permanently based in the villages. Open days and farmer visits to experimental sites were also organised. In 1999, two farmers of the peri-urban zone of Ségou felt cropping and feeding sweet sorghum to dairy cows was not beneficial because of the increase milk produced did not cover for the poor stover yield of the sweet sorghum compared to landrace sorghum and because its poor quality due to bad conservation. However they changed mind in 2000 following the price increase of the industrial feed supplement ABH. In the site of San farmers were more enthusiasts and noticed that sweet sorghum diets seemed to have accelerate the return in heat of several cows. They also noticed that sweet sorghum increased the drinking water requirements of the cows.

At regional level, contacts with development agencies permitted an exchange of information on tested technologies and their expected regional impacts.

**Table 42:** Ex-post economic assessment of tested cattle fattening technologies (kondogola, 2001)

| Parameters measured over the 3 months of the fattening period and expressed per ox | 3 kg ABH + 2 kg bran | 3 kg ABH + 1.5 kg Molasses + 20 g MC | 2 kg ABH + 2 kg Molasses 65 g urea + 20 g MC |
|---|---|---|---|
| Number of cattle fattened | 6 | 7 | 7 |
| Weight gain (Kg /ox /3months) | 7 | 47 | 42 |
| Final weight final (kg/oxl) | 257 | 282 | 284 |
| Cattle sale price (CFA $kg^{-1}$) | 377 | 452 | 414 |
| Manure (kg/ox/3months) | 756 | 978 | 1 008 |
| Manure sale price (CFA $kg^{-1}$) | 5 | 5 | 5 |
| Gross product (CFA/ox /3months) | 100 669 | 121 638 | 112 108 |
| Total cost of inputs (CFA/3month) | 127 500 | 245 730 | 254 367 |
| Input costs (CFA/ox /3months) | 21 250 | 35 104 | 36 338 |
| Veterinary care (CFA/ox /3months) | 3 000 | 3 000 | 3 000 |
| Labour (CFA/ox /3months) | 1 500 | 1 500 | 1 500 |
| Total variable cost (CFA/ox /3months) | 25 750 | 39 604 | 40 838 |
| Cattle purchase price (CFA/ox) (1) | 60 000 | 60 000 | 60 000 |
| Cattle purchase price (CFA/ox) (2) | 80 000 | 80 000 | 80 000 |
| Net benefit (CFA/ox /3months)(1) | 14 919 | 22 034 | 11 270 |
| Net benefit (CFA/ox /3months) (2) | -5 081 | 2 034 | -8 730 |
| Marginal rate of return (%) (1) | na | 51 | -24 |

## 3. Sites in rainfed lands in Niger
### 3.1. Farming systems and rain-fed benchmark sites in Niger

Rainfed crop-livestock systems are found throughout the semi-arid zone in Niger. Seven benchmark sites initially considered were grouped into three benchmark sites based on bioclimate drier in Diffa and Tahoua (rainfall < 450 mm), intermediate in Tillabery (450-600 mm) and wetter in Maradi and Gaya ( >600mm)(Table 1). Surveys and trials were developed in 15 villages spread around the country from Diffa in the East to Tillabery in the West and distributed along the bioclimatic gradient from the wet to the dry end of the semi-arid zone. Each of the benchmark site hosts other IFAD funded projects. In spite of differences in geology (very poor and sandy soils on sandstone substrate in the Tillabery and Kollo areas; finer and more fertile brown soils on limestone in Maradi and Tahoua and alluvial soils along the Niger river in Kollo and the Komadougou river in Diffa area), population density, history and culture, agricultural activity in the benchmark sites is centred on subsistence crop livestock systems.

Income from crop-livestock activities is often complemented by off-farm activities that men engage in during the long dry season. The main crop and staple is millet with sometimes sorghum grown in low-lying areas or more fine textured soils. Millet is often intercropped with dual-purpose cowpea more common in the west of the country and the bean-cowpea more common in the central and eastern parts. Cowpea beans as well as haulms are widespread source of cash. Locally important other cash crops include groundnut and cassava in the south, choufa, onions and garlic in the centre, pepper in the east, sesame, bambara nut and okra every where. These crops are often grown and managed by women on small plots of land.

Livestock assets vary widely between wealth categories and between benchmark sites (Table 44). In terms of livestock species, goats are most abundant followed by cattle and sheep, respectively. Generally, livestock are reared in an extensive manner with animals grazing on natural pastures, fallows and crop residues. Seasonal movement in search of pasture is common, but the direction, duration and timing of such movements is largely dependent on local feed situation at each site. Sheep fattening, using harvested stovers and haulms, bush hay and farm by-products, is widely practiced throughout the country. Table 43 provides a list of feeds and supplements commonly used in Niger.

**Table 43**. Feeds and supplements given to animals by wealth category and gender in study villages in Niger

| Village | Men | | | Women | | |
|---|---|---|---|---|---|---|
| 1 | High | Medium | Low | High | Medium | Low |
| Ala Dalamaram | 1, 2, 3 | 1, 2, 3 | 1, 2 | 2 | 2 | - |
| Tam | 1, 2, 3, 4, 6 | 1,2,4 | 1,2 | 1 | 1 | 1 |
| Hardo Alto | 1, 2, 4, 5, 6 | - | - | 1 | - | - |
| Doguéraoua | - | - | - | 1 | 2 | - |
| Guidan Tanyo | - | - | - | 2 | 1 | 1 |
| Nadara I | - | - | - | 2 | 2 | 1 |
| Nadara II | - | - | - | - | - | - |

1 = Millet bran; 2 = Cereal stover; 3 = Cotton seed cake; 4 = Legume hay; 5 = Bush hay; 6 = Salt lick;

**Table 44**. Average resource endowments by class category and information on IFAD and FAO funded projects in study villages in Niger

| Benchmark site | Villages | Category | Labor (adult equiv.) | Land Area (ha) | Cattle (head) | Sheep (head) | Goats (head) | Nature of IFAD Project |
|---|---|---|---|---|---|---|---|---|
| Diffa | Ala Dalamaram | High | | 9.5 | 16 | 1 | 6 | * 1993-95 Credit for agricultural equipment<br>* 1998 - NRM |
| | | Medium | | 3.7 | 6 | 2 | 7 | |
| | | Low | | 1.8 | 2 | 0 | 7 | |
| Maradi | Tam | High | | 5 | 18 | 4 | 25 | * 1999- NRM |
| | | Medium | | 4.2 | 13 | 2 | 5 | |
| | | Low | | 4.2 | 1 | 0 | 6 | |
| | Hardo Alto | High | | 10.9 | 28 | 27 | 18 | - |
| | | Medium | | 10.9 | 8 | 8 | 9 | |
| | | Low | | 10.5 | 6 | 7 | 11 | |
| | Doguéraoua | High | | 11 | 13 | 7 | 15 | * 1993 Credit for fertilizer<br>* 1996-7 Education |
| | | Medium | | 5.6 | 6 | 4 | 7 | |
| | | Low | | 6.7 | 0 | 0 | 5 | |
| | Guidan Tanyo | High | | 16.9 | 9 | 12 | 17 | * 1993- Credit for agricultural equipment |
| | | Medium | | 13.6 | 2 | 8 | 15 | |
| | | Low | | 6.2 | 0 | 0 | 3 | |
| Tahoua | Nadara I | High | | 6.4 | 1 | 5 | 6 | - |
| | | Medium | | 6.3 | 1 | 7 | 8 | |
| | | Low | | 3.9 | 0 | 1 | 1 | |
| | Nadara II | High | | 9 | 2 | 4 | 2 | * 1990-96 Credit for agricultural equipment<br>* 1998 Well digging |
| | | Medium | | 8.5 | 1 | 0 | 2 | |
| | | Low | | 5.2 | 0 | 1 | 1 | |
| Dantiandou | Banizoumbou Tigo Tegui, Kodey villages | High | 8.4 | 25.2 | 12.7 | 4.1 | 5.1 | * 1999- FAO funded project to strengthen farmers associations, and promote access to inputs through credit |
| | | Medium | 4.5 | 21.4 | 0.7 | 1.0 | 1.1 | |
| | | Low | 4.9 | 9.1 | 1.1 | 1.4 | 1.0 | |
| | Fulani camps attached to the villages | High | 5.4 | 12.7 | 15.4 | 22.5 | 13.1 | |
| | | Low | 5.8 | 8.7 | 4.5 | 11.9 | 4.6 | |

**Description of communities and social assets**

Customary rights regulate access to cropland. The first settlers in any village own most of the land. Other settlers obtain access to land through the land-owning families. The criteria, suggested by the farmers themselves, used to classify farm households into different wealth categories differ between communities (table 45). And the proportions under which farm households are distributed in the three or four wealth categories also differ between communities (table 46). Except in the relatively better-off Maradi area where households are equally distributed across the three wealth categories, there is a preponderance of households in the poor category at other benchmark sites.

As the table shows, the range of feeds and supplements used by women to feed to their animals in the study villages in Niger is limited compared to what is used by men. This underlines the importance of providing appropriate economic incentives to women to empower and make it possible for them to utilize the proposed technologies.

Table 45. Criteria suggested by farmers for classification of households into different wealth categories in study villages in Niger

| Benchmark site | Villages | Category | Classification criterion |
|---|---|---|---|
| Diffa-Tahoua | Ala Dalamaram | High | Ability to manage pepper farm with own resources |
| | | Medium | Ability to manage pepper farm, with credit at end |
| | | Low | Credit at start of season to manage pepper farm |
| | Tam | High | Agric. Equipment and self sufficient in food |
| | | Medium | Min agric. equipment and self sufficient in food |
| | | Low | No agric. equipment and dependent on own labour |
| | Nadara I | High | 500 bundles of millet; 1000 kg of cowpea |
| | | Medium | 150-200 bundles of millet; 500 kg of cowpea |
| | | Low | 50 bundles of millet; 50 kg of cowpea |
| | Nadara II | High | 400-500 bundles of millet; 1000 kg of cowpea |
| | | Medium | 200-300 bundles of millet; 500 kg of cowpea |
| | | Low | 50-100 bundles of millet; 100-150 kg of cowpea |
| Tillabéry | Banizoumbou<br>Youloua<br>Boundou<br>Banka dey<br>Tondi kiboro | High | 675±171 bundles of millet; 584 ± 376 kg of cowpea |
| | | Medium | 256±129 bundles of millet; 232 ± 112 kg of cowpea |
| | | Low | 70 ± 26 bundles of millet; 120 ± 72 kg of cowpea |
| | | Very low | 26 ± 5 bundles of millet; 28 ± 24 kg of cowpea |
| | Tigotégui<br>Katanga<br>Bagoua<br>GourouYena<br>Bani Koubaye | High | 1133 ± 179 bundles of millet; 1496 ± 992 kg of cowpea |
| | | Medium | 512 ± 143 bundles of millet; 704 ± 504kg of cowpea |
| | | Low | 118 ± 38 bundles of millet; 140 ± 48 kg of cowpea |
| | | Very low | 46 ± 20 bundles of millet; 14 ± 8 kg of cowpea |
| | Kodey<br>Bodol | High | 650 ± 216 bundles of millet; 400 ± 280 kg of cowpea |
| | | Medium | 317± 170 bundles of millet; 184 ± 152 kg of cowpea |
| | | Low | 93 ± 41 bundles of millet; 56 ± 72 kg of cowpea |
| | | Very low | 24 ± 10 bundles of millet; 14 ± 18 kg of cowpea |
| Maradi<br>Gaya | Hardo Alto | High | 300-400 bundles of millet |
| | | Medium | 100-200 bundles of millet |
| | | Low | 50-60 bundles of millet |
| | Doguéraoua | High | 200-300 bundles of millet |
| | | Medium | 150-200 bundles of millet |
| | | Low | 50-100 bundles of millet |
| | Guidan Tanyo | High | 500 bundles of millet |
| | | Medium | 200 bundles of millet |
| | | Low | 15 bundles of millet |

**Table 46.** Distribution of households by wealth category in the Niger benchmark sites.

| Wealth category | Benchmark sites | | | | | |
|---|---|---|---|---|---|---|
| | Diffa - Tahoua | | Tillabery | | | Maradi |
| High | 6.5 | 11.7 | 13.0 | 13.3 | 9.3 | 27.6 |
| Medium | 24.2 | 13.3 | 28.0 | 19.7 | 30.8 | 26.4 |
| Low | 69.3 | 75.0 | 37.0 | 35.0 | 31.3 | 28.0 |
| Very low | - | - | 22.0 | 29.1 | 28.6 | - |

Although the perception of the severity of constraint differs between gender and benchmark sites, soil fertility is largely recognized as a major factor limiting agricultural productivity across the benchmark sites (Table 47). To address this problem, different soil fertility amelioration options were tested taking into consideration the peculiarities of the local farming systems.

**Table 47**. Proportion (%) of cultivated land with soil fertility problem by gender and wealth category in the study villages in Niger.

| Villages | Women | | | Men | | |
|---|---|---|---|---|---|---|
| Wealth groups | High | medium | low | high | medium | Low |
| Ala Dalaram | 10 - 30 | 10 - 30 | 30 - 50 | 10 | 100 | 33 |
| Tam | 50 - 70 | 30 – 50 | 100 | 100 | 50 | 100 |
| Hardo Alto | 30 - 50 | - | - | 100 | 100 | 20 |
| Doguéraoua | 100 | 100 | 30 - 50 | 50 | 100 | 100 |
| Guidan Teigno | 50 - 70 | 50 – 70 | 50 - 70 | 100 | 70 | 85 |
| Nadara I | 100 | 30 - 50 | 30 - 50 | 100 | 100 | 40 |
| Nadara II | 50 - 85 | 100 | 100 | 100 | 50 | 90 |

Unlike cropland which are managed individually by each household, under a range of land tenure situations, water and grazing resources are managed communally, this includes herbaceous and browses from the non arable rangelands but also from the land fallowed, and after grain harvest it extend to crop residues and weeds in the field. Establish the quantitative role of the livestock in the use of forage resources and the recycling of organic matter and nutrients through excretions requires a detailed and comprehensive data base on the movement of livestock over the year cycle. This was done at the Tillabéry benchmark sites, where a spatial data base or geographic information system was established over 500 km$^2$ that included data on 10 villages and 532 households. This information system represents a valuable tool in the diagnosis of the farming systems of western Niger, as well as a solid framework for the prediction of the results of technological and policy adoptions through the use of simulation models. However, only the first steps of that procedure were covered in 2001: Diagnostic of crop-livestock farming systems and development of an information system on the structure and dynamics of the households, the classification of farms in representative households and the parameterisation of household models for each representative farm type the following steps include the development and use of simulation models, which currently are in the developmental phase.

The detailed soil map allowed a geographical stratification of land use system and natural resource management options. Land use map drawn for years 1950, 1975, 1992, 1994, 1995, 1996 revealed the large and accelerating increase in the area cropped during the last half of the century. It also indicated that the three sites differed by their present land use situation with land cropped areas ranging from 35, 45 to 65% of the total arable land of each village. The interrelation of the land use maps with the household and herd data bases showed that the increase in the proportion of land cropped followed human population density, and was accompanied by an increase in the annual mean livestock density from 7 to 12 Tropical Livestock Units per $km^2$ despite the parallel reduction in range and fallow lands. However, the annual mean covers seasonal fluctuations due to livestock movements in and out of the village land that are increasing in amplitude at higher density. The nutrient balances were calculated per land use type, season, and per year for each village site. Work was done to adapt an existing bio-economic model at the village level (Barbier B.,1996 ) to the type of village data base build in this project . Work was done to adapt an existing multi goal linear programming model (Hengsdijk and Kruseman, 1993 ) developed to test economic and technical scenarios at farm level to the farming systems of western Niger. The model was adapted by K. Sissoko to farming systems in the cotton belt of southern Mali (Sissoko, 1998). Finally, 'Nutmon', a participative monitoring method set up to assess the nutrient use and balance at farm level and associated mathematical model 'Nutschell' have been explored as tools to establish nutrient balances at selected benchmark sites (Busqué, 2002). Once the Fakara database adapted to the structure of the NUTMON farm database, soil nutrient balances were performed for N, P and K by a process of querying on the base of the following nutrient flows: grazing forage uptake, excreta deposition during grazing time, corralling and manual manure application and harvest of crop products. At this stage atmospheric deposition, nitrogen fixation, N and K leaching, erosion and human excreta were not considered.

Grazing forage uptake was estimated using a simple mathematical model. Input data to the model consisted on size, type and number of livestock herds grazing in the area, spatial distribution of vegetation types, biomass and fields, and a gross indication of the different grazing routes used along a whole year. The model estimated the amount grazed of different forage *feeds* by each individual herd in individual fields for each month of a year. Forage *feeds* refer to different land use types (cropland, fallow and rangeland), crops (millet, cowpea and sorghum); plant groups (herbaceous and ligneous) and plant components (edible standing, edible litter, browse material). Selection among the *feeds* on offer in each grazing route was simulated as a function of aerial biomass availability, palatability, nitrogen concentration and digestibility of the *feeds*, overall grazing pressure and livestock browsing predisposition (Figure 4a and 4b).

Excreta deposition was simulated in a simple way, considering the amount of faeces as the product of forage ingestion by its digestibility, their nutrient content as the average values per season from experiments in the area, and urine nutrients were assumed to be lost. Corralling and crop harvest values were directly obtained from the Fakara database. Tables 3, 4 and 5 summarize the flows of nutrients for the four sources considered: grazing, excreta deposited while grazing, manuring and crop harvesting. Average values are given at different levels of aggregation according to the type of farmer, site within the region and land use. Livestock managers differentiate from village farmers in their lower average area of managed land, especially under fallow, and their much higher area of land manured, in this case corralling the animals at night (Table 47a). It is this difference in area of land manured what produces the contrasted nutrient balances, positive for livestock managers and negative for village farmers (Tables 47b,c,d).

**Figure 4a**. Prediction of the monthly forage selection by cattle in the study area in 1995-96 using the forage grazing model. Observed values for fallow/cropland/rangeland were 75/5/20% from June to September, 20/73/7% in October-November, 39/54/7% from December to February and 49/46/5% from March to May (data from Schlecht, 1998).

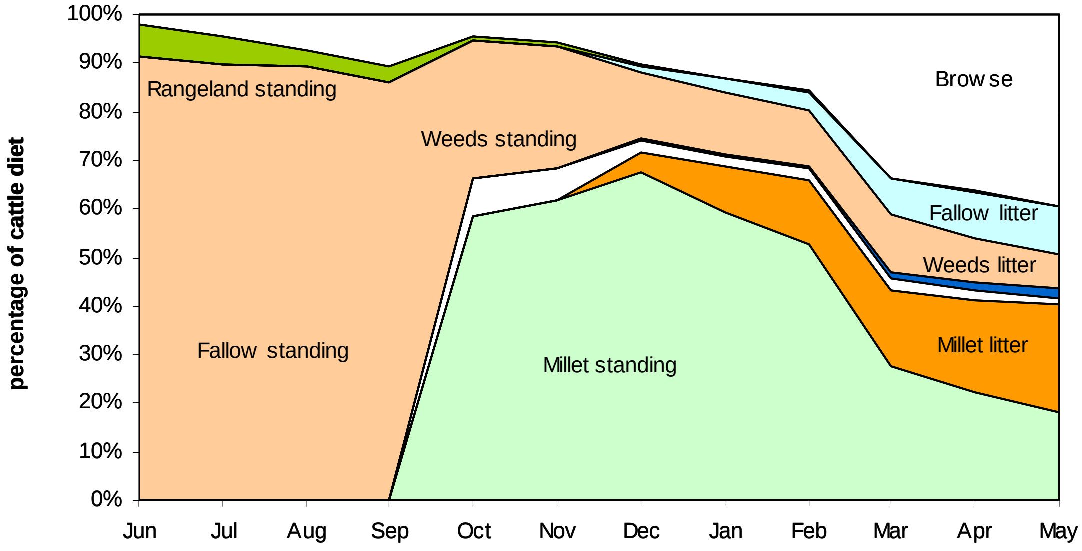
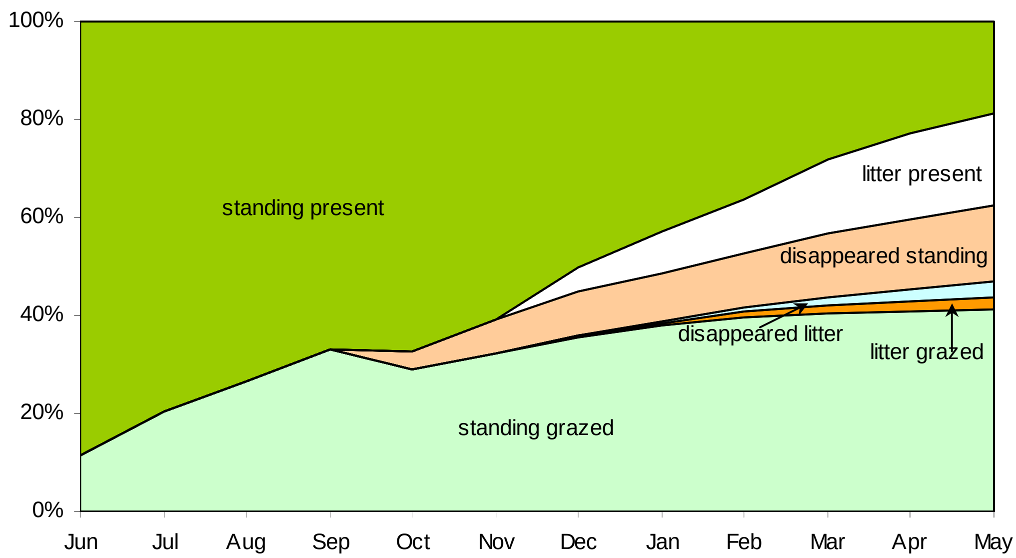



**Figure 4b.** Predicted average percentage of vegetation components weighed for all vegetation types (millet, weeds, fallow herbaceous, rangeland herbaceous and browse) during 1995-96. Grazed and disappeared pools are expressed as cumulative values.



Fallows show small negative nutrient balances globally and for each site, though fallows specifically managed by farmers of the livestock managers group have high positive values. From these results it is inferred that other sources of nutrient inputs must have a significant effect in producing positive balances in fallows, and thus fit to the soil nutrient depletion-replenishment cycle of the crop-fallow rotation.

**Table 47a**. Land use distribution in the Fakara region according to the type of farmer (village and livestock managers) and to one of the three sites defined (Banizoumbou, Kodey and Tigo-Tegui).

| Group | Sites | Land use | Area/farm (ha) | std | Area manured / farm (ha $yr^{-1}$) | std | no of farms | Number of farms not manuring |
|---|---|---|---|---|---|---|---|---|
| Village farmers | Bani | Crop | 11.1 | 9.73 | 0.39 | 1.05 | 154 | 99 |
| | | Fallow | 19.0 | 16.38 | 0.39 | 1.42 | | 124 |
| | Kodey | Crop | 12.5 | 8.80 | 0.45 | 1.25 | 56 | 23 |
| | | Fallow | 5.1 | 4.59 | 0.13 | 0.90 | | 49 |
| | Tigo | Crop | 12.5 | 9.84 | 0.04 | 0.17 | 123 | 83 |
| | | Fallow | 12.8 | 13.16 | 0.00 | | | 114 |
| Farmers livestock managers | Bani | Crop | 10.3 | 7.42 | 2.37 | 2.34 | 42 | 1 |
| | | Fallow | 11.0 | 13.59 | 0.69 | 1.06 | | 5 |
| | Kodey | Crop | 10.0 | 7.79 | 3.59 | 2.99 | 58 | 2 |
| | | Fallow | 1.8 | 2.17 | 0.33 | 0.53 | | 13 |
| | Tigo | Crop | 8.9 | 15.43 | 1.27 | 1.31 | 58 | 6 |
| | | Fallow | 8.7 | 13.27 | 0.91 | 1.19 | | 9 |
| Communal rangeland | Bani | | 456.1 | | | | | |
| | Kodey | | 481.6 | | | | | |
| | Tigo | | 698.8 | | | | | |

**Table 47b**. Nitrogen flows and balance (kg $ha^{-1}$) in the Fakara region according to the type of farmer (village and livestock managers) and to one of the three sites defined (Banizombou, Kodey and Tigo-Tegui).

| **Group** | **Site** | **Land use** | **N uptake** | | **N excreta** | | **N harvest** | | **N manure** | | **N balance** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mean | std | mean | std | mean | std | mean | std | mean | std |
| **Village farmers** | Bani | Crop | -2.2 | 3.69 | 0.8 | 0.76 | -10.0 | 7.42 | 29.0 | 56.33 | -11.1 | 9.46 |
| | | Fallow | -3.9 | 1.86 | 1.1 | 0.86 | | | 5.4 | 8.70 | -2.7 | 1.24 |
| | Kodey | Crop | -1.3 | 0.70 | 0.6 | 0.34 | -11.2 | 8.14 | 117.7 | 253.20 | -11.5 | 8.07 |
| | | Fallow | -5.5 | 2.31 | 1.3 | 0.77 | | | 2.4 | 2.03 | -4.1 | 1.77 |
| | Tigo | Crop | -1.9 | 1.18 | 0.7 | 0.46 | -9.6 | 4.59 | 206.2 | 223.16 | -10.6 | 4.56 |
| | | Fallow | -3.8 | 1.59 | 1.1 | 0.63 | | | 151.8 | | -2.7 | 1.17 |
| **Farmers livestock managers** | Bani | Crop | -3.0 | 2.40 | 1.1 | 0.85 | -9.8 | 6.36 | 48.3 | 23.18 | 1.0 | 12.57 |
| | | Fallow | -9.9 | 25.82 | 2.8 | 7.09 | | | 140.2 | 99.97 | 8.1 | 17.16 |
| | Kodey | Crop | -1.9 | 0.96 | 1.4 | 0.98 | -10.1 | 5.36 | 28.3 | 17.44 | 1.0 | 12.20 |
| | | Fallow | -6.0 | 3.51 | 2.5 | 1.80 | | | 56.9 | 29.86 | 9.5 | 18.29 |
| | Tigo | Crop | -2.0 | 1.14 | 0.8 | 0.44 | -7.7 | 4.74 | 50.7 | 19.88 | 4.7 | 20.47 |
| | | Fallow | -4.9 | 1.85 | 1.4 | 0.68 | | | 73.5 | 42.27 | 5.4 | 10.97 |
| **Communal rangeland** | Bani | | -2.3 | | 1.3 | | | | | | -1.1 | |
| | Kodey | | -1.6 | | 1.9 | | | | | | 0.3 | |
| | Tigo | | -1.0 | | 0.6 | | | | | | -0.4 | |

**Table 47c**. Phosphorus flows and balance (kg ha$^{-1}$) in the Fakara region according to the type of farmer (village and livestock managers) and to one of the three sites defined (Banizombou, Kodey and Tigo-Tegui).

| Group | Site | Land use | P uptake | | P excreta | | P harvest | | P manure | | P balance | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mean | std | mean | std | mean | std | mean | std | mean | std |
| Village farmers | Bani | Crop | -0.2 | 0.25 | 0.1 | 0.10 | -1.0 | 0.63 | 4.2 | 7.82 | -1.0 | 0.76 |
| | | Fallow | -0.4 | 0.17 | 0.2 | 0.12 | | | 0.8 | 1.23 | -0.2 | 0.10 |
| | Kodey | Crop | -0.1 | 0.05 | 0.1 | 0.04 | -1.0 | 0.55 | 16.8 | 35.71 | -0.9 | 0.57 |
| | | Fallow | -0.5 | 0.23 | 0.2 | 0.12 | | | 0.3 | 0.26 | -0.3 | 0.15 |
| | Tigo | Crop | -0.1 | 0.09 | 0.1 | 0.06 | -0.9 | 0.33 | 30.0 | 32.22 | -1.0 | 0.33 |
| | | Fallow | -0.4 | 0.15 | 0.2 | 0.09 | | | 21.3 | | -0.2 | 0.09 |
| Farmers livestock managers | Bani | Crop | -0.2 | 0.18 | 0.2 | 0.11 | -0.9 | 0.45 | 6.3 | 2.91 | 0.7 | 1.56 |
| | | Fallow | -0.9 | 2.22 | 0.4 | 0.99 | | | 21.7 | 14.44 | 1.9 | 3.11 |
| | Kodey | Crop | -0.1 | 0.07 | 0.2 | 0.13 | -1.0 | 0.40 | 4.0 | 2.57 | 0.7 | 1.57 |
| | | Fallow | -0.6 | 0.36 | 0.4 | 0.26 | | | 9.0 | 4.71 | 1.8 | 2.99 |
| | Tigo | Crop | -0.1 | 0.08 | 0.1 | 0.06 | -0.8 | 0.38 | 6.8 | 2.74 | 1.0 | 2.81 |
| | | Fallow | -0.5 | 0.17 | 0.2 | 0.10 | | | 11.4 | 6.94 | 1.1 | 1.74 |
| Communal rangeland | Bani | | -0.2 | | 0.2 | | | | | | 0.0 | |
| | Kodey | | -0.1 | | 0.3 | | | | | | 0.2 | |
| | Tigo | | -0.1 | | 0.1 | | | | | | 0.0 | |

**Table 47d**. Potassium flows and balance (kg ha$^{-1}$) in the Fakara region according to the type of farmer (village and livestock managers) and to one of the three sites defined (Banizombou, Kodey and Tigo-Tegui).

| Group | Site | Land use | K uptake | | K excreta | | K harvest | | K manure | | K balance | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mean | std | mean | std | mean | std | mean | std | mean | std |
| Village farmers | Bani | Crop | -4.2 | 6.60 | 0.2 | 0.23 | -4.6 | 5.08 | 6.9 | 11.44 | -8.5 | 8.95 |
| | | Fallow | -2.5 | 1.08 | 0.3 | 0.25 | | | 1.2 | 1.72 | -2.2 | 0.91 |
| | Kodey | Crop | -2.3 | 1.43 | 0.2 | 0.10 | -6.2 | 7.29 | 24.4 | 48.06 | -8.2 | 6.83 |
| | | Fallow | -4.9 | 2.05 | 0.4 | 0.22 | | | 0.5 | 0.22 | -4.6 | 1.88 |
| | Tigo | Crop | -3.8 | 2.31 | 0.2 | 0.14 | -3.9 | 3.97 | 47.5 | 49.13 | -7.4 | 4.17 |
| | | Fallow | -2.8 | 1.22 | 0.3 | 0.19 | | | 31.1 | | -2.5 | 1.07 |
| Farmers livestock managers | Bani | Crop | -5.7 | 4.57 | 0.3 | 0.25 | -4.4 | 5.52 | 13.7 | 6.18 | -6.1 | 6.53 |
| | | Fallow | -4.8 | 8.54 | 0.8 | 2.11 | | | 40.0 | 27.94 | 0.4 | 5.23 |
| | Kodey | Crop | -3.3 | 1.63 | 0.4 | 0.28 | -4.2 | 4.50 | 8.1 | 4.94 | -3.7 | 5.29 |
| | | Fallow | -5.6 | 3.41 | 0.7 | 0.52 | | | 16.4 | 8.58 | -1.1 | 5.58 |
| | Tigo | Crop | -3.9 | 2.30 | 0.2 | 0.13 | -3.0 | 3.55 | 14.7 | 5.81 | -2.7 | 7.61 |
| | | Fallow | -3.4 | 1.27 | 0.4 | 0.20 | | | 21.1 | 12.08 | -0.5 | 3.06 |
| Communal rangeland | Bani | | -0.5 | | 0.4 | | | | | | -0.1 | |
| | Kodey | | -0.8 | | 0.5 | | | | | | -0.2 | |
| | Tigo | | -0.3 | | 0.2 | | | | | | -0.1 | |

Access to external inputs, and particularly fertilizers is determinant to enhance productivity and improve nutrient balances. This justifies a survey of the professionals traders of agricultural inputs carried out at national level in Niger by INRAN. The policies and laws that apply for each type of inputs classified in: fertilizer, pesticides, seeds and veterinary products were described in the context of their history. A survey was carried out on a sample of 26 traders and 11 societies from different parts of the country, to document their motivation (profit for 62%), the type of input commercialised (46% were mix importers, 30 specialised in fertilisers, 12 in pesticides, 7 in seeds and 5 in veterinary products), the source of these products (Nigeria provide more than half), the source of capital (73 personal, 23 including relatives, only 4% including bank credit), prices, main opportunities and constraints faced. With the exception of pesticides they are no control on quality of the inputs, the on the composition of fertilizer is common, their no control of prices and prices at farm gate are high (190 CFA kg of NPK 15-15-15, 7000 CFA per litter of pesticide). Credit facilities are poor for the small traders and for the farmers. However, the later are increasingly getting access to Rural Credit through Farmers Association.

### 3.2. Technological options for more efficient crop-livestock integration

In Niger, village resources maps and transects established for 9 villages highlighted the importance of crop-livestock interactions, crop diversification and management of crop residues in farmer's perception of nutrient management. The implications on nutrient cycling of the extent and location of different soil types (upland sandy soils, lowland clay soils and shallow soils), land use units (area cropped, fallowed and non arable rangelands), infrastructures (village, camps, water points, livestock paths) were stressed. The differences between communities in relation to their geographical location and resource endowment were highlighted in sampling contrasting sites across the country.

From the calculations of the organic matter, nitrogen and phosphorus balances in three village sites of western Niger it appeared that the aggregate fodder intake by livestock on a year round basis only reached 12 to 20% of total feed production, including crop residues. This poor efficiency of livestock grazing compared to other agro-ecosystems is due, in part, to the large unpalatable fraction (about 60% of the millet stovers and 30 to 60% of weeds and herbage), to the land use and the management of cropland that differ between sites, and also to the strong seasonality in availability and quality of the forages. As a consequence feed digestibility by cattle especially may drop below 40%, reducing livestock performances. Strategic mineral, protein and energetic feed supplements were tested to enhance dry season digestibility and livestock performances. Nutrition experiments were implemented on reproductive cows and for sheep fattening. In both cases supplements tested were either mineral (Urea, Phosphate, Mineral complex) or protein and energetic. The impact of such nutrition supplements on the quantity and quality of the excretions produced was assessed systematically.

The quantity of manure depends on the number of livestock resident in the village land. The bio-economic model developed by Bruno Barbier was successfully adapted to western Niger village site (Barbier B., 1998). The results highlighted the importance of seasonal transhumance as a risk management strategy as well as the importance of seasonal human emigration and off-farm income in village economy. However little is known on the influence of transhumance on reproductive cattle productivity and a trial assess this influence. As livestock transhumance is commonly practiced in Niger to help match feed availability with demand, on-farm experiments were conducted to combine wet season transhumance with late dry season supplementation in order to assess the trade-offs of these technologies on cattle performance, especially reproduction which is vital to extensive livestock production systems.

The balance between forage intake and excretion by livestock was negative over most of the landscape except for the 3 to 8% of the cropped lands that are partially manured each year, mostly by corralling livestock at night during the dry season. However, the average rate of manuring by corralling was estimated as high as 12.7 ± 4.9 t DM $ha^{-1}$ for cattle and 6.8 ± 4.5 for small ruminants with mean corralling duration of 20 and 15 days respectively and areas of corral sites aggregated over the year cycle only covered 05 to 1.5% of the land cropped. Even if the effect of the manure deposited is expected to last of 4 to 5 years, only 3 to 8% of cropped lands benefit from the manure amendment applied in rotation one year out of 4 or 5. This justifies research carried out on station and on-farm to improve the efficiency of soil amendment by corralling. At the Tillabéry benchmark sites, manure obtained through corralling of animals on soils covered with or without litter bedding was tested together with dry season supplementation of cattle. In addition, on-station experiments were conducted in Sadoré to assess the efficacy of manure amendments by corralling cattle, sheep or goats, at different seasons of the year and different stocking rates. These on-station experiments under controlled conditions are needed to assess the residual effects of manure and to obtain detailed data on the balance of organic matter and nutrients in the soils

Even if its efficiency is improved corralling, or more generally using livestock manure will not be sufficient to ensure nutrient balance of the system all other components of the soil nutrient balance being considered, external inputs in nitrogen and phosphorus are required. Thus, trials were made of cheap ways to efficiently input inorganic fertilizer on the cropped lands that did not received manure. In addition, combinations of manure and hill placement of inorganic fertilizer were also tried in this area. Along the north-south gradient from Gaya to Sadore, manure, hill placement of inorganic fertilizer (DAP or NKP 15-15-15) and broadcasting of local rock phosphate were the main soil amendments tested on millet. . In the shallow soils around Tahoua, placement of compost in dug holes ('zaï') with or without rock phosphate was tested on millet

In the crop-livestock interactions, legume crop such as cowpea play a key role as they provide superior fodder for livestock, rich food and cash, and in addition have the potential to symbiotically fix air nitrogen, reducing the deficit balance for Nitrogen. Yet the proportion of land devoted to cowpea (as well as other legume crop: groundnut, bambara nut, dolichos...) is small, cowpea often being cropped in association with millet or sorghum at less than 1000 hills per ha. Ways to increase the proportion of legume, especially cowpea in the production systems were explored with the farmers

### 3.3. Ex-ante economic assessment

Only for sheep fattening (table 47 e) was an ex-ante economic assessment performed either because the trials had been started before the on set of the project or because of the lack of sufficiently precise quantitative parameters (such as in the case of the wet season transhumance-dry season supplementation trial with cattle.)

Considering the diversity of farmer practices in the composition of sheep fattening diet and the implication on its profitability, the trial consisted in testing three levels of cowpea haulms that constitute the protein rich component of the diet, but also the most expensive. The sheep are also given 400 g of millet bran $d^{-1}$, mineral lick and sorghum stover ad libitum. Compared to a control diet without cowpea haulms (table 47 e) the three treatments are beneficiary with marginal rates of return on the investment of cowpea that decrease slightly from 525 to 448% as the rate of cowpea in the diet increases from 300 to 900 g per day.

**Table 47e**: Ex-ante marginal analysis of alternative diets to fatten sheep. The diet include various levels of cowpea haulms, 400 g of millet bran and ad libitum sorghum stover.

| Parameters measured over 56 days of fattening period and expressed per sheep | Cowpea haulms in the diet g $d^{-1}$ | | | |
|---|---|---|---|---|
| | 0 | 300 | 600 | 900 |
| Initial mean weight (kg) | 30 | 30 | 30 | 30 |
| Final weight final (kg/oxl) | 35 | 38 | 40 | 42 |
| Weight gain (Kg) | 5 | 8 | 10 | 12 |
| Sheep purchase price (CFA) | 20000 | 20000 | 20000 | 20000 |
| Sheep sale price (CFA) | 25 375 | 28 500 | 31 000 | 33 600 |
| Millet bran, sorghum stover | 2 000 | 2 000 | 2 000 | 2 000 |
| Cowpea cost (CFA) | 0 | 500 | 1000 | 1500 |
| Labour cost (CFA) | 1600 | 1600 | 1600 | 1600 |
| Veterinary and equipment cost (CFA) | 500 | 500 | 500 | 500 |
| Total cost (CFA) | 24 100 | 24 600 | 25 100 | 25 600 |
| Net benefit (CFA) | 1 275 | 3 900 | 5 900 | 8 000 |
| Marginal rate of return (%) | ref | 525 | 462 | 448 |

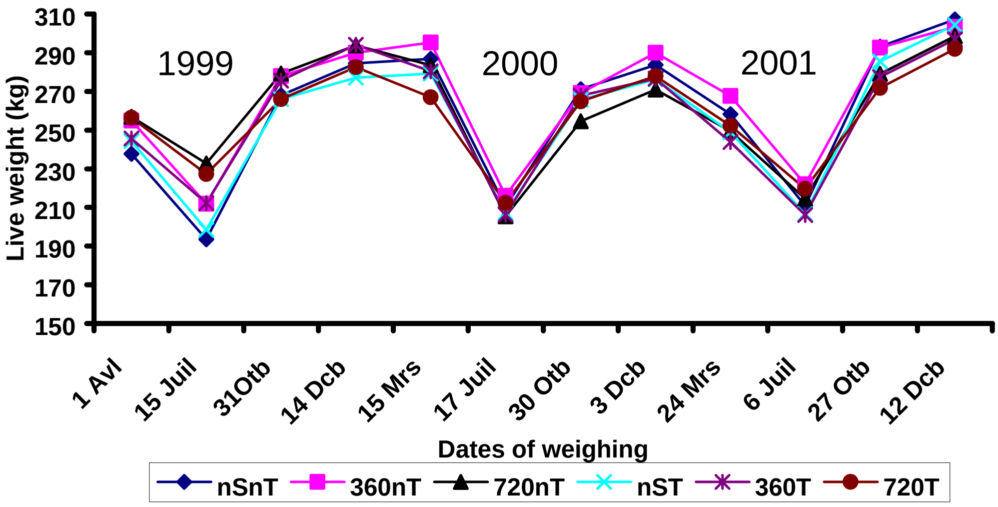
### 3.4. Project implementation, trials and results

Wet season transhumance and strategic feed supplementation of reproductive cows

The effects of wet season transhumance and dry season supplementation were evaluated on dairy cow productivity. This study was initiated in 1998 in the village of Katanga (2º48 E, 13º32 N) with 60 heifers and enlarged in mid 1999 to include 45 heifers in the village of Gorou-yena (2º44 E, 13º30). Forty of these 45 cows had been subject to same type of transhumance trial in 1998 but instead of the millet-bran feed supplementation they experienced a test of mineral supplementation in the late dry season with urea dissolved in the drinking water and phosphorus mixed in local nitrate-chlorine salt licks (natron). The results of this mineral supplementation were not significant and the risks for animal health involved in their implementation incited to stop this particular trial after the second year. In 2001, the first herd completed the fourth cycle of transhumance while the second completed its third transhumance cycle. In both herds, cows were allotted to six treatments in a factorial arrangement of three levels of dry season supplementation (including 0, 360 and 720 g of millet bran equivalent to 333 and 666 g dry matter per cow and per day to with are added respectively 0, 2 or 4g Simple Super phosphate per heifer per day) and two levels of wet season transhumance (with and without). 360 g of millet bran provide about 50 g crude protein and 3 MJ metabolizable energy). All animals were vaccinated against Pleuropneumonia, Anthrax, and Pasteurelosis once a year and treated against external and internal parasites and other infections. Excretions produced by the cows were collected by corralling at night during the supplementation period in the late dry season in order to test the influence of the supplementation on the quality of manure and its effect on millet yield. Response variables measured include yearly and seasonal weight changes, body condition scores, fecal concentration of OM, N and P, calving and weaning rates, birth and weaning weights, weight changes of calves before weaning, and milk production of the lactating cow (during the early dry season, at the return from transhumance only).

In all treatments, cows weight varied with seasons, gaining 60 to 90 kg during the late wet and early part of the dry season and loosing 50 to 80 kg during the late dry and early wet season (Fig 5).

**Figure 5:** Live weight changes of cows per treatment irrespective of the physiological status of the cows




The seasonal changes combined with the changes due to the physiological status of the cows, pregnant cows gaining more or loosing less weight than dry cows, and lactating cows gaining less and loosing much more weight than dry cows (Table 48).

**Table 48.** Seasonal mean daily weight gain (DWG), or loss, in g per head of cows depending on their physiological status: three last month of gestation, 7 first month of lactation, and all other cases (dry cows, early pregnant and late lactating cows).

| Periods | Feeding treatments millet bran (g $d^{-1}$) | No pregnant | | Pregnant | | Lactating | |
|---|---|---|---|---|---|---|---|
| | | Mean DWG (g) | s.d | Mean DWG (g) | s.d | Mean DWG (g) | s.d |
| Late dry | 0 | -290 | 326 | -177 | 709 | -764 | 646 |
| | 360 | -330 | 370 | -290 | 307 | -702 | 745 |
| | 720 | -273 | 389 | -217 | 327 | -773 | 918 |
| Wet | 0 | 646 | 502 | 521 | 617 | 462 | 508 |
| | 360 | 578 | 398 | 443 | 334 | 293 | 629 |
| | 720 | 530 | 593 | 483 | 362 | 248 | 548 |
| Harvest | 0 | 317 | 364 | 391 | 188 | 69 | 485 |
| | 360 | 319 | 363 | 323 | 224 | 189 | 369 |
| | 720 | 368 | 319 | 252 | 206 | 217 | 250 |
| Early dry | 0 | -87 | 564 | -225 | 451 | -431 | 567 |
| | 360 | -76 | 441 | -285 | 935 | -589 | 626 |
| | 720 | -112 | 345 | -333 | 544 | -515 | 561 |

Daily supplementation with either 360g or 720g of locally available millet bran given during the last four month of the dry season significantly reduced cows weight losses during the late dry season (Table 48). Conversely, wet season transhumance did not affect cow weight gain during the wet season. However, both supplementation and transhumance, enhanced pregnancy (table 49) and calving rates (table 50). Initial observations also point to a possible effect of dry season supplementation and transhumance on the duration of pregnancy. Compared with cows that remained in the village, supplemented transhumant cows appeared to have longer gestation periods (table 51).

**Table 49:** Pregnancy rate of cow after three years depending on the supplementation and transhumance treatments.

| Treatments | Number of cows | Rate of first pregnancy | Rate of second pregnancy | Overall rate of pregnancy |
|---|---|---|---|---|
| 0 g Millet bran | 43 | 90.7 | 23.3 | 113.9 |
| 360 g Millet bran | 35 | 94.3 | 34.3 | 128.6 |
| 720 g Millet bran | 36 | 91.7 | 72.2 | 163.9 |
| All sedentary | 60 | 90.0 | 31.7 | 121.7 |
| All transhumant | 54 | 94.4 | 29.6 | 124.1 |

**Table 50**: Calving rate of cows depending on supplementation and transhumance treatments.

| Treatments | | Cows Number | First ca(%)lving | Second calving (%) | Aggregated calving (%) |
|---|---|---|---|---|---|
| 0 g $d^{-1}$ | Sedentary. | 25 | 60.0 | 12.0 | 69.7 |
| | Transhumant | 18 | 83.3 | 5.5 | |
| 360 g $d^{-1}$ | Sedentary. | 17 | 82.3 | 11.7 | 85.7 |
| | Transhumant | 18 | 88.8 | 5.5 | |
| 720 g $d^{-1}$ | Sedentary. | 18 | 83.3 | 5.5 | 86.1 |
| | Transhumant | 18 | 88.8 | 11.1 | |
| All | Sedentary. | 60 | 86.7 | 10.0 | 75.2 |
| | Transhumant | 54 | 98.1 | 5.6 | 86.9 |
| | All | 114 | 92.4 | 7.8 | 82.6 |

**Table 51**: Effect of the late dry season supplementation and wet season transhumance on pregnancy duration (days)

| Treatments | | First pregnancy | | Second pregnancy | | Means | | Means by supplement | |
|---|---|---|---|---|---|---|---|---|---|
| | | m | s.d | m | s.d | m | s.d | M | s.d |
| 0 g $d^{-1}$ | Sedentary. | 267 | 2 | 285 | 2 | 276 | 13 | 278 | 13 |
| | Transhumant | 278 | 15 | 275 | - | 276 | 15 | | |
| 360 g $d^{-1}$ | Sedentary. | 277 | 18 | 292 | - | 284 | 9 | 284 | 10 |
| | Transhumant | 283 | 8 | 281 | - | 282 | - | | |
| 720 g $d^{-1}$ | Sedentary. | 281 | 13 | 275 | - | 278 | - | 277 | 10 |
| | Transhumant | 278 | 13 | 279 | 11 | 276 | 12 | | |
| All | Sedentary. | 285 | 18 | 284 | 1 | 280 | 11 | | |
| | Transhumant | 278 | 12 | 278 | 11 | 278 | 13 | | |
| | All | 277 | 12 | 281 | 7 | 278 | 10 | 279 | 11 |

Feed supplementation and transhumance had no effect on live weight change of calves. However, the year and season of birth had significant influence calf growth.

To try and assess the role of strategic supplementation on reproductive cow productivity the assessment was done base on the number of alive cows born per year and per cow, and on the average weight of calves at six and twelve months. The productivity (table 51b) is expressed in kg of weaned calves per adult female per year. In  average over the two herds and across years there were no differences between the two levels of supplementation which appear to increase productivity by about 30%.

**Table 51b**: Effect of dry season supplementation on the productivity of the cows expressed as average number, and kg of calves weaned over a year.

| Suppl. Treat. | Gourou Yéna herd | | | Katanga herd | | | All | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cows # | Calves # | Calve weight /cow | Cows # | Calves # | Calve weight /cow | Cows # | Calves # | Calve weight /cow |
| 0 | 19 | 14 | 21.5 | 24 | 16 | 19.2 | 43 | 30 | 20.3 |
| 360 | 15 | 15 | 29.3 | 20 | 17 | 23.7 | 32 | 47 | 26.5 |
| 720 | 15 | 12 | 23.5 | 20 | 20 | 29.9 | 35 | 47 | 26.7 |
| All | 49 | 41 | 24.8 | 64 | 53 | 24.2 | 103 | 94 | 24.6 |

Improved salt licks tested with sheep on fattening

Surveys conducted all over Niger in 1999 described the use of local mineral sources in small ruminant husbandry. Samples of these mineral licks were collected and analyzed in 2001. Chemical composition allowed grouping them into 3 types based on their content in Ca (more than 4%, from to 1% and less than 1% (table 52). Intake by fattening sheep and impact on their weight gains were measured and compared with a lick made of 3% calcinated bones, 2% of cement, 30% of sodium salt, 26% of Malbaza limestone and 39% of Tahoua rock phosphate in order to set the Ca to P ratio at 1.6 (table 53)

**Table 52**:  Mineral concentrations in locally available mineral licks in Niger.

| Mineral lick group | Lick origin and name | Mineral composition (%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | N | P | Ca | NaCl | Fe | K |
| Calcium rich | Bourmoidi | 0.12 | 0.02 | 4.03 | 85.5 | 0.15 | 1.89 |
| Calcium fair | Foga | 0.14 | 0.29 | 1.68 | 56.4 | 0.14 | 1.04 |
| | Kojéméry | 0.13 | 0.90 | 2.16 | 90.0 | 0.04 | 2.7 |
| | Bitoa | 0.26 | 0.10 | 1.35 | 32.0 | 0.07 | 2.62 |
| Calcium poor | Kolontey | 0.1 | 0.01 | 0.42 | 85.5 | 0.01 | 0.76 |
| | Sabonbirni | 0.07 | 0.01 | 0.81 | 68.0 | 0.02 | 0.91 |
| | Natron Tchad | 0.03 | 0.01 | 0.50 | 84.0 | 0.05 | 0.44 |
| | Bana | 0.02 | 0.01 | 0.24 | 68.0 | 0.04 | 0.49 |
| | Tigguida | 0.02 | 0.08 | 0.29 | 61.0 | 0.05 | 0.33 |
| | Fachi | 0.01 | 0.02 | 0.64 | 92.0 | 0.04 | 1.17 |
| | Bilma | 0.004 | 0.02 | 0.46 | 53.0 | 0.05 | 5.46 |

**Table 53**: Ca and P concentration in mineral licks, including INRAN designed lick, Kollo.

| Components | Components (%) | Ca (%) | | P (%) | |
|---|---|---|---|---|---|
| | | component | lick | component | Lick |
| Bones pouder | 3 | 33.43 | 1.003 | 13.0 | 0.39 |
| Sodium Salt | 30 | 1.75 | 0.525 | 1.1 | 0.33 |
| Cement | 2 | - | - | - | - |
| Limestone | 26 | 29.0 | 7.54 | 0.25 | 0.065 |
| Rock phosphate | 39 | 0 | 0 | 12.3 | 4.797 |
| lick | 100 | - | 9.068 | - | 5.582 |
| Requirements (g $kg^{-1}$) | 100 | - | 9 | - | 5.62 |

A sheep fattening trial was  initiated late in 2001 and it still on-going. It was arried out by 16 farmers at Nadara (Tahoua site), each farmer fattened four sheep with diets composed of 300 g of millet bran, ad libitum bush hay and amonts of cowpea haulms ranging from 0 to 300, 600  and 900 g $d^{-1}$ per animal. The refusal and feces collected are used to make compost which is used in turn to manure millet fields cropped on marginal land with the Zaï technique. Results are not yet available.

A sheep feeding trial was conducted in Kollo to assess the intake of mineral licks by sheep and impact of the licks on their weight gains depending on the nature of the lick. Three local sources of mineral lick were compared to a lick designed by INRAN and to a control were sheep had no access to licks. In each treatment seven sheep weighing initially between 20 and 25 kg were fed 400g of cowpea halms, 750 g of wheat bran and Echinochloa hay ad libitum. for 90 days. Lick intake by sheep differed significantly with higher intake for the calcium poor (and more salty?) licks: 6.2 ± 1.9 g $d^{-1}$ per animal. The Inran lick coming second with 3.3 ± 1.1 g $d^{-1}$ per animal while the other licks were less attractive with intake of 2.4 ± 1.0 and 1.2 ± 0.3 g $d^{-1}$ per animal for calcium fair and rich licks respectively. Access to licks enhanced weight gains more with the calcium poor and the Inran made lick than with calcium fair of rich licks (table 54).

**Table 54**:  Weight gains of sheep during 90 days of fattening depending on the type of mineral lick they had access to, Kollo, 2001.

| Lick | Initial weight (kg) | Mean weight gains (g $d^{-1}$ per animal) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 15/10 – 29/10 | 30/10 - 13/11 | 14/11 - 28/11 | 28/11 - 13./12 | 14/12 - 28/12 | 28/12 - 12/01 | Overall mean |
| Ca + | 20.6 ± 0.4 | 237 ± 107 | 91 ± 102 | 82 ± 73 | 136 ± 73 | 139 ± 96 | 107 ± 97 | 132 ± 56 |
| Ca ± | 19.7 ± 0.2 | 271 ± 76 | 113 ± 74 | 137 ± 92 | 129 ± 56 | 189 ± 47 | 177 ± 87 | 169 ± 58 |
| Ca - | 19.0 ± 0.2 | 246 ± 123 | 206 ± 128 | 101 ± 53 | 205 ± 46 | 192 ± 89 | 173 ± 80 | 187 ± 48 |
| Inran | 17.8 ± 0.5 | 233 ± 97 | 181 ± 90 | 115 ± 53 | 138 ± 64 | 201 ± 40 | 168 ± 86 | 173 ± 42 |
| No | 25.2 ± 1.7 | 217 ± 99 | 129 ± 133 | 90 ± 84 | 121 ± 86 | 130 ± 132 | 126 ± 70 | 135 ± 42 |

The overall mean of feces production by the fattened sheep was 620.6 ± 22.4 g $d^{-1}$ per animal with no differences with the type of mineral lick.

Energetic, proteic and mineral supplementation for sheep fattening

A sheep fattening trial was carried out at Nadara, village of intervention of the IFAD-Badiguichiri project  (Tahoua benchmark) with 16 farmers (including 2 women). Each farmer had four male sheep between 32 and 34 kg initial weight, 18 to 26 months of age, tethered and fed for 52 days with 400 g $d^{-1}$ of millet bran with an unlimitated access to sorghum stover, all animals being vaccinated and drenched prior to the trial onset. The feed components of the diets were analysed for total N, P, NDF, ADF and lignine (table 55a).

**Table 55a**. Biochemical composition of the three main feed components in the diets of fattened sheep at Nadara (Niger, 2002).

| Diet components | DM | Ash | N | P | NDF | ADF | Lignin |
|---|---|---|---|---|---|---|---|
| | % | % DM | %DM | %DM | % | % | % |
| Cowpea haulms | 92.6 | 8.5 | 15.8 | 0.29 | 38.8 | 27.1 | 4.9 |
| Sorghum stover | 92.8 | 6.6 | 3.6 | 0.12 | 59.0 | 37.9 | 5.0 |
| Millet bran | 92.4 | 6.3 | 15.1 | 0.50 | 33.1 | 11.6 | 4.5 |

**Table 55b**: Feed intake and weight gain of sheep fattened with different quantities of cowpea haulms. Nadar, Tahoua, Niger, 2002

| Cowpea haulms in diet<br>Quantité de fanes de niébé<br>(g $d^{-1}$) | 0 | 200 | 400 | 600 | P ><br>- | LSD<br>- |
|---|---|---|---|---|---|---|
| Total dry matter intake: | | | | | | |
| ▪ (g $d^{-1}$)g/j | 1223.0$^{bc}$ | 1152.5$^{c}$ | 1297.0$^{b}$ | 1460.6$^{a}$ | 0.0001 | 81.06 |
| ▪ (g $kg^{-0.75}$) | 80.7$^{bc}$ | 78.0$^{c}$ | 86.4$^{b}$ | 99.2$^{a}$ | 0.0001 | 5.77 |
| Partial intake(g $d^{-1}$): | | | | | | |
| ▪ Cowpea haulms | 0$^{d}$ | 156$^{c}$ | 311$^{b}$ | 467$^{a}$ | 0.0001 | 155.21 |
| ▪ Millet bran | 350.5$^{a}$ | 351.3$^{a}$ | 349.9$^{a}$ | 347.8$^{a}$ | 0.9561 | 12.81 |
| ▪ Sorghum stover | 872.2$^{a}$ | 645.4$^{b}$ | 635.7$^{b}$ | 645.7$^{b}$ | 0.0001 | 82.35 |
| Initial weight (kg) | 34.6 | 33.0 | 33.4 | 32.2 | - | - |
| Final weight (kg) | 40.7$^{a}$ | 39.7$^{a}$ | 40.9$^{a}$ | 40.6$^{a}$ | 0.7765 | 2.42 |
| Total weight gain (kg) | 6.2$^{b}$ | 6.7$^{ab}$ | 7.5$^{ab}$ | 8.5$^{a}$ | 0.0938 | 1.88 |
| Daily weight gain (g $d^{-1}$) | 118.4$^{b}$ | 128.6$^{ab}$ | 143.9$^{ab}$ | 162.4$^{a}$ | 0.0924 | 36.23 |
| Conversion index (kg intake / kg weight gain) | 11.94 | 10.87 | 11.54 | 11.12 | 0.9734 | 4.84 |

a, b, c means different at 0.01

There is a very slight increase of weight gains with the increasing quantity of cowpea haulm offered to the sheep but not generally not significant except for the highest proportion of cowpea (600g per day) which give weight gains superior to the control (table 55b). The weight gains were relatively high in all treatments. This indicates the good value of sorghum stover as bulk feed for fattening sheep. Total feed intake increases with the quantity of cowpea haulm offered to the sheep from 200 to 600g per day. However the feed intake of the control sheep not offered any cowpea haulms was superior to the intake for 200 g (table 55b). By partial substitution the intake in sorghum stover decreased with the increase in cowpea haulms.

<u>Improved corralling of livestock to better manage soil fertility for millet crop</u>

In western Niger, manuring practices by corralling livestock at night were monitored in ten villages over a full year cycle. In a sub-sample, the effects of these practices on the millet yields were measured at the end of the 1998 growing season. The results confirmed the limited extent of the field area manured annually within the village cropped lands, because of relatively low stocking rates (5 to 10 Tropical Livestock Unit $km^{-2}$), livestock mobility and also the high rate of manure application practiced in the corral sites. Indeed the rates of manure application by corralling as measured over a sample of 60 farmers year round in 1998 were 13 t DM $ha^{-1}$ for cattle and 7t DM $ha^{-1}$ for sheep and goats (Hiernaux et al 1998). Compared to unmanured plots in the same field, millet yield in 1998, the year following manure deposition, was increased by 72% in cattle and 112% for small ruminant corral sites.

In 1998 and 1999, two manuring trials were carried out in farmers fields at Gourou Yena, associated with cattle feeding or transhumance trials. The objective of these trials was to compare the effect of excretions produced by supplemented animals with those that are not supplemented. Heifers received N and/or P supplements as urea in drinking water or phosphate mixed with 'natron' (local salt lick). The manure of heifers receiving different mineral or energetic supplements was 'harvested' by corralling the animals at night on fields subsequently planted to millet. The effect of supplementation was also compared with direct applications of urea and/or phosphate to the plant with and without addition of millet stem litter. The experiment carried out in 1998 was repeated on a second field in 1999. Residual effects of the manuring in 1998 and 1999 were monitored over years till 2001 on millet crop with no additional inputs. However, in collaboration between IFDC and ILRI the measure of the third-year residual effect of the manuring treatment was completed by the application in two bocks out of four of placed NPK fertilizer at to 2 kg $P_2O_5$ ha$^{-1}$ in order to test relay application of small doses of placed inorganic fertilizer after and history of organic application. In 1998 and 1999, no yield differences were observed with the application of N and P either through mineral supplements given to cattle corralled at night on cropped lands or through inorganic fertiliser applied directly to crops in fields manured by corralling unsupplemented cattle. In 2000, millet yields confirmed the residual effect of manure application on millet yields six tons DM of manure of none supplemented heifers giving grain yields of 527 ± 56 kg ha$^{-1}$ versus 298 ± 54 kg ha$^{-1}$ in the control in one experiment. Mineral supplementation of the diet had significant effect on the quality of the manure which had similar effect on millet yield than the direct application of the equivalent amount of fertilizer in the case on Nitrogen (738 ± 39 versus 732 ± 78 kg ha$^{-1}$ ) and a diminished effect in case of phosphorus (634 ± 48 versus 676 ± 46 kg ha$^{-1}$) or of combined nitrogen and phosphorus (1225± 49 versus 672 ± 40 kg ha$^{-1}$).

In another trial conducted in Kantanga with the cow used in the transhumance-supplementation trial, the effects of manure produced by heifers fed different quantities of millet bran supplement during the late dry season were measured on subsequent millet crop. The trial was conducted using different manure rates (6, 12 and 18 t DM ha$^{-1}$) combined with or without inorganic fertilizer (4 kg of NPK 15-15-15). This experiment was repeated on a second field with a one-year lag, and the residual effect of the treatment with no other inputs were monitored till 2001. In 1998, despite below average and ill distributed rainfall, millet response to combined application of organic and mineral fertilizer was encouraging. Hill-placed phosphorus fertiliser applied at a low rate (2 g Di-Ammonium- Phosphate per hill) in addition to moderate manure application (6t DM ha$^{-1}$) increased millet yields yield by 350 kg grain ha$^{-1}$, more than the sum of the yields due to each separate amendment In 2000, the results of the cattle corralling experiment, confirmed the large effect of manure application on millet yields six tons DM of manure of none supplemented heifers giving grain yields of 754 ± 34 versus 531 ± 91 kg ha$^{-1}$ in the control. The millet yield response to the amount of manure was linear between 0 and 18 t DM ha$^{-1}$. However supplementation with different quantities of millet bran had little effects on grains although they increased stover yields...

Table 57 Residual effect of manure application (0,6,12,18 t DM kg DM ha$^{-1}$) during 1999 dry season (Field KA1) or during 2000 dry season (field KA2) on grain, stover and total above ground yields of millet.

| CHAMP | Manure t DM ha$^{-1}$ | Grain kg DM ha$^{-1}$ | Stover kg DM ha$^{-1}$ | Total plant kg DM ha$^{-1}$ | Grain to head % | Grain to stover % |
|---|---|---|---|---|---|---|
| KA1 | 0 | 241.0 | 992.5 | 1091.5 | 61.0 | 25.0 |
| | 6 | 593.5 | 2355.2 | 2590.2 | 58.5 | 25.5 |
| | 12 | 808.7 | 3265.7 | 3591.5 | 58.2 | 25.5 |
| | 18 | 1068.7 | 4283.0 | 4710.3 | 59.4 | 25.0 |
| KA2 | 0 | 330.0 | 992.1 | 1097.0 | 63.6 | 35.3 |
| | 6 | 604.2 | 1937.7 | 2142.7 | 60.0 | 32.3 |
| | 12 | 707.9 | 3353.3 | 3708.0 | 59.1 | 26.5 |
| | 18 | 828.8 | 3156.0 | 3489.8 | 58.8 | 27.2 |

In 2001, the second year residual effect was measured on the first field, while the first year effect was measured on the second field. Residual effects of corralling cattle three or two year ago were very strong on yields and linearly oriented with rate of manure application (table 57).

Grain yields difference to the control were ranging from 275 to 500 kg grain /ha for first year residual effect in KA2 and from 345 to 790 in KA1 for second year residual effect in KA1, and this for the range of 6 to 18 t of DM feces applied per hectare. Stover yields followed the same trend. In KA1 the second year residual effect was higher than the first year residual effect in KA2, perhaps because of a lag time in sowing date. Also the second year effect was higher than the first year effect recorded on the same field last year with sub-optimal rainfall conditions. Effect of cattle supplementation with millet bran on millet response to manure was not significant, while complementary mineral fertilisation with placed NPK was still systematically increasing yields three years after application in the case of field KA1 (Table 58).

**Table 58**. Residual effect of 6t of cow manure deposited by corralling during the dry season 1999 (KA1) or 2000( KA2), with or without combined application of 6g NPK 15-15-15 per hill, on the grain and stover yield of millet cropped for the third or second consecutive year in 2001.

| Field | Manure treatment | Grain yield ( kg DM ha$^{-1}$) No fertilizer | Grain yield ( kg DM ha$^{-1}$) NPK 6 g hill$^{-1}$ | Stover yield ( kg DM ha$^{-1}$) No fertilizer | Stover yield ( kg DM ha$^{-1}$) NPK 6 g hill$^{-1}$ |
|---|---|---|---|---|---|
| KA1 | no manure | 278.1 | 166.8 | 1187.5 | 602.5 |
| | 6t; no suppl. | 561.0 | 647.8 | 2105.6 | 2377.1 |
| | 6t, 360 g d$^{-1}$ | 537.7 | 608.5 | 2240.3 | 2608.3 |
| | 6t, 720 g d$^{-1}$ | 583.8 | 687.7 | 2341.7 | 2710.6 |
| KA2 | no manure | 330.0 | 624.2 | 992.1 | 2071.9 |
| | 6t; no suppl. | 439.3 | 562.9 | 1383.7 | 1838.8 |
| | 6t, 360 g d$^{-1}$ | 739.0 | 721.5 | 2302.4 | 2161.3 |
| | 6t, 720 g d$^{-1}$ | 624.2 | 548.3 | 2071.9 | 1923.3 |

Low yield were obtained on farm fields where corralling was done four years ago (Table 59). And millet grain yield responded significantly (*$p=0.05$*) to microdose P fertilizer but was barely responsive crop residues applied as soil amendment (*$p=0.08$*).

A collaborative trial (involving ILRI, ICRISAT, IFDC and the University of Hohenheim) was initiated in 1997, on-station at Sadoré, to assess the effects of the quality, quantity and timing of application of feces and urine by corralling either cattle or sheep and goats on a field formerly cropped with millet or on a young fallow. The experiment was repeated on a second field with a one-year lag .The residual effects of the corralling done in 1997 and 1998 were measured every year till 2001 on millet crop with no additional input.

Additional fields were manured during the rainy seasons of 1998, 1999 and 2000. In addition to measuring millet yields and nutrient uptake by millet, the decomposition of the millet litter and the feces deposited by cattle, sheep and goats were monitored as well as their changing chemical composition. Soils were regularly sampled; soil moisture profile monitored using neutron probes (0-6m) and capacitance probe (0-1.8m) in selected treatments. Nutrient leaching was also assessed at monthly intervals ($NO_3$) or at the onset and the end of the growing season (organic C, exchangeable bases, P) by destructive soil sampling.

**Table 59.** Effect of fertilizer and crop residues on millet yields in fields with four-year residual effect of cattle manure.

| Residue | P rate (kg $P_2O_5$ $ha^{-1}$) | Yield (kg $ha^{-1}$) | |
|---|---|---|---|
| | | Grain | Stover |
| Without residues | 0 | 255 | 1047 |
| | 2 | 299 | 1262 |
| | | | |
| With residues | 0 | 296 | 1333 |
| | 2 | 377 | 1715 |

Probability levels: *P=0.05 (*fertilizer); *p=0.08 (*residue)

The results of the on-station corralling experiment allowed establishing the response curve of millet yield with the rate of manure application. The yields of millet cropped the first year were approximately linear with the rate of manure application, grain yields ranging from 700 to 2100 kg $ha^{-1}$ for 0 to 14 t $ha^{-1}$ of manure. Manure of small ruminants resulted in slightly higher yields than cattle manure at all rates of application. Residual effects of corralling on millet cropped a second year without additional intervention were only significant at the highest rate of manure application (14t $ha^{-1}$ of manure). There were no consistent difference in the response to treatment observed in previously fallowed land and previously cultivated land. The residual effects of manure applied 2, 3 and 4 years ago were significant and proportionate to the amount of manure applied (Table 60).

**Table 60**. Millet yields in manuring experiment (Sadoré, Niger), all treatment means of grains, harvested stalks and total above ground mass of millet calculated for each year and plot aggregates.

| Field | Year | n | grains (kg DM $ha^{-1}$ ) | | harvested stalks (kg DM $ha^{-1}$) | | total millet mass (kg $ha^{-1}$) | |
|---|---|---|---|---|---|---|---|---|
| | | | mean | stderr | mean | stderr | Mean | stderr |
| 5A | 97 | 170 | 634.0 | 18.5 | 1772.1 | 72.8 | 3407.4 | 106.0 |
| | 98 | 170 | 409.2 | 21.8 | 718.2 | 33.7 | 1254.5 | 59.5 |
| | 99 | 170 | 681.2 | 19.6 | 1843.1 | 48.7 | 3216.4 | 84.2 |
| | 00 | 170 | 406.3 | 13.9 | 1042.6 | 29.5 | 1799.8 | 50.5 |
| | Mean | | 533.4 | 14.4 | 1345.4 | 37.7 | 2421.3 | 62.9 |
| 1B | 98 | 170 | 1400.7 | 40.4 | 2959.2 | 112.7 | 4894.7 | 170.2 |
| | 99 | 170 | 921.2 | 23.4 | 2559.1 | 66.3 | 480.5 | 110.2 |
| | 00 | 170 | 462.9 | 20.2 | 1134.4 | 43.9 | 1994.4 | 76.2 |
| | 01 | 171 | 364.1 | 15.4 | 1053.4 | 2.5 | 1765.6 | 70.4 |
| | Mean | | 787.0 | 21.5 | 1920.0 | 57.1 | 3272.6 | 92.5 |
| total mean | | | 660.6 | 14.6 | 1633.5 | 37.6 | 2848.2 | 60.5 |

For example, aggregate millet yields difference to the control over 3 years reached 237±10 kg of grain $ha^{-1}$ and 568±26 kg stover $ha^{-1}$ per tonne of manure applied in the first year (Table 34). These yields indicate excellent rates of return of 50% for N and 47% for P and these figures will be confirmed through on-going chemical analysis. In 2001 the residual effect of manure applied 4 ago (field 1B) by corralling cattle, sheep and goats were significant and linear with the rate of manure applied: 45 kg millet grain $ha^{-1}$ and 114 kg stover $ha^{-1}$ per tonne of manure applied 4 years ago (Table 60). The response to manure applied 5 years ago (field 5A) is still significant and linear with rate of application but yields are in average inferior to the control yields by -12 kg grain $ha^{-1}$ and -73 kg stover $ha^{-1}$ per tonne of manure applied 5 years ago for a range of 0 to 14t manure $ha^{-1}$. Only application of 10 and 14t DM of manure yield more than the unmanured control. Aggregated millet yields over 4 years reached

281±12 kg of grain ha$^{-1}$ and 670±32 kg stover ha$^{-1}$ per tonne of manure applied on the first year additional to the control yield (table 61).

**Table 61.** Millet yields in manuring experiment (Sadoré, Niger), all treatment means of yield difference to unmanured control (millet stalks returned to soil every year) for grains, harvested stalks and total above ground mass of millet calculated for each year and plot aggregates.

| Field | Year | n | Yield difference to unmanured control | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | grains (kg DM ha$^{-1}$) | | harvested stalks (kg DM ha$^{-1}$) | | total millet mass (kg DM ha$^{-1}$) | |
| | | | mean | stderr | mean | stderr | mean | stderr |
| 5A | 97 | 150 | 354.6 | 15.8 | 1010.6 | 78.8 | 2239.4 | 98.5 |
| | 98 | 150 | 163.7 | 23.1 | 286.0 | 35.9 | 500.3 | 63.2 |
| | 99 | 150 | 361.3 | 20.5 | 822.0 | 47.7 | 1500.0 | 83.1 |
| | 00 | 150 | 182.2 | 14.6 | 401.6 | 29.7 | 729.4 | 51.3 |
| | aggregate | | 1060.6 | 57.0 | 2509.9 | 152.3 | 4955.3 | 241.4 |
| 1B | 98 | 150 | 783.6 | 39.4 | 1905.1 | 113.1 | 3025.8 | 169.1 |
| | 99 | 150 | 285.5 | 23.3 | 801.3 | 59.0 | 1351.1 | 99.5 |
| | 00 | 150 | 286.8 | 21.4 | 584.8 | 48.1 | 1061.5 | 82.5 |
| | 01 | 150 | 203.1 | 16.1 | 525.1 | 44.9 | 903.3 | 73.5 |
| | Aggregate | | 1559.5 | 89.0 | 3871.7 | 238.1 | 6347.1 | 384.0 |
| total aggregate | | | 1310 | 54.7 | 3165.8 | 146.1 | 5651.2 | 229.1 |

Aggregated incremental millet yields over 4 years in average over the two fields reached 281±12 kg of grain ha$^{-1}$ and 670±32 kg stover ha$^{-1}$ per tonne of manure applied on the first year additional to the control yield. Aggregate incremental yields over four years were not different for rates of manure application ranging from 4 to 14 t DM ha$^{-1}$ (Table 62, 63). However, the lower rate of 2t DM ha$^{-1}$ yielded significantly more.

**Table 62.** Relative millet grain yields in manuring experiment (Sadoré, Niger), yield difference (kg DM ha$^{-1}$ per tone of manured applied) to the un-manured control (crop residues returned) in the first years and aggregate first two, three and four years after manuring depending on rates of manure application from 2 to 14 t DM ha$^{-1}$.

| Field | Manure T DM ha$^{-1}$ | First year | | Two first years | | Three first years | | Four years | |
|---|---|---|---|---|---|---|---|---|---|
| | | mean | stderr | mean | stderr | mean | stderr | mean | stderr |
| 5A + 1B | 2 | 174 | 17 | 209 | 22 | 298 | 28 | 370.7 | 35.3 |
| | 4 | 125 | 8 | 169 | 11 | 229 | 14 | 264.6 | 17.3 |
| | 6 | 104 | 7 | 145 | 9 | 207 | 11 | 239.2 | 13.4 |
| | 10 | 95 | 10 | 126 | 15 | 184 | 16 | 213.5 | 19.5 |
| | 14 | 71 | 9 | 145 | 20 | 209 | 29 | 240.2 | 29.8 |
| | All rates | 126 | 6 | 168 | 8 | 237 | 10 | 281.2 | 12.4 |

In a trial initiated in 2000 in a farmer's field, in Gourou Yena, the effect of alternative bedding material at the corral stops were tested (no bedding, 2t DM millet stover, 2t DM of branches of Guiera senegalensis) at three corralling duration (equivalent to 6, 12 and 18 t DM ha$^{-1}$). In 2000 yields responded to the rate of manure application with grain yields from 202 to 356, 345 and 435 kg ha$^{-1}$ for the control and 6,12 and 18t of manure respectively. In 2001, the residual effect was assessed: using 2t DM of Guiera senegalensis branches increased second year yields by 80 kg grain and 387 kg stover ha$^{-1}$ while 2t millet stem bedding only increased second yields by 16 kg grain and 119 kg of stover. Aggregated over the two years, grain and stover yields increased linearly to the rate of manure application irrespective of the feed supplementation with millet bran and phosphorus given to cows. The use of a 2t DM ha$^{-1}$ of Guiera leaves bedding increased yields by 141 kg ha$^{-1}$ grain and 341 kg stover while a 2t DM ha$^{-1}$ of millet stem bedding increased yields by 74 kg ha$^{-1}$ grain and 113 kg stover.

**Table 63.** Relative millet stalk yields in manuring experiment (Sadoré, Niger), yield difference (kg DM ha$^{-1}$ per tone of manured applied) to the un-manured control (crop residues returned) in the first years and aggregate first two, three and four years after manuring depending on rates of manure application from 2 to 14 t DM ha$^{-1}$.

| Field | Manure t DM ha$^{-1}$ | First year | | Two first years | | Three first years | | Four years | |
|---|---|---|---|---|---|---|---|---|---|
| | | mean | stderr | mean | stderr | mean | stderr | mean | stderr |
| 5A + 1B | 2 | 401 | 52 | 520 | 61 | 706 | 73 | 860.4 | 92.5 |
| | 4 | 305 | 22 | 415 | 29 | 567 | 37 | 656.1 | 43.9 |
| | 6 | 249 | 20 | 351 | 27 | 475 | 30 | 552.1 | 35.2 |
| | 10 | 268 | 28 | 336 | 40 | 452 | 48 | 526.5 | 57.2 |
| | 14 | 231 | 24 | 388 | 49 | 528 | 68 | 604.8 | 69.3 |
| | All rates | 307 | 17 | 418 | 21 | 568 | 26 | 669.7 | 31.9 |

Another corralling experiment was carried out in 2001 at Sadoré to assess the respective contributions of urine and feces to the fertilization effect of night corralling by either cattle or sheep-goats. The assessment was carried out with male animals fit with fecal collection bags in order to separate feces from urine. The separate application was also compared to joint application, and this is repeated at three levels of application. The effects were measured on millet grain and stover yields.The separate application of urine and faeces indicate a 2 to 6 times larger response to the urine than to the faeces deposited by cattle and small ruminant corralled at night. (table 64). The response to the joint application being slightly superior to the sum of the separate application responses at low rate of application becoming inferior at the higher rate of application. Further analysis indicates with faeces there was a superiority of grain yield response for small ruminant while cattle urine had superior response than small ruminants ones (table 65).

**Table 64**. Millet yields response to separate and joined application (M) of cattle, sheep and goats faeces (F) and urine (U) at three level of application (4, 8 and 12 nights). Field 5A3 Sadoré, Niger.

| Corralling Nights | Treatments | Mean difference to the un manured control yields (kg DM/ha) | |
|---|---|---|---|
| | | grains | Stalks |
| 4 | F | 86.0 | 404.8 |
| | U | 526.7 | 1267.9 |
| | F + U | 612.7 | 1672.7 |
| | M | 639.3 | 1827.4 |
| 8 | F | 125.5 | 410.7 |
| | U | 468.1 | 1422.6 |
| | F + U | 593.6 | 1833.3 |
| | M | 689.2 | 2321.4 |
| 12 | F | 286.3 | 910.7 |
| | U | 512.7 | 1803.6 |
| | F + U | 799.0 | 2714.3 |
| | M | 593.1 | 2000. |

**Table 65**. Millet yields response to separate and joined application (M) of cattle, sheep and goats faeces (F) and urine (U) at one level of application (4 nights). Field 5A3 Sadoré, Niger.

| Corralling duration nights | Treat -ment | Grain yield difference to the non-manured control yields (kg DM/ha) | | | | Stalks yield difference to the non-manured control yields (kg DM/ha) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cattle | | Sheep-Goat | | Cattle | | Sheep-Goat | |
| | | mean | s.e. | mean | s.e. | mean | s.e. | mean | s.e. |
| 0 | Contr | 236 | 79 | 236 | 79 | 875 | 149 | 875 | 149 |
| 4 | F | 245 | 73 | 399 | 6 | 1012 | 263 | 1548 | 195 |
| | U | 851 | 33 | 674 | 26 | 2190 | 331 | 2095 | 284 |
| | M | 754 | 365 | 997 | 195 | 1619 | 1170 | 2786 | 824 |
| 8 | F | 255 | 63 | 468 | 87 | 1000 | 189 | 1571 | 234 |
| | U | 791 | 78 | 617 | 100 | 2167 | 208 | 2429 | 82 |
| | M | 903 | 138 | 947 | 136 | 3226 | 787 | 3167 | 383 |
| 12 | F | 490 | 114 | 554 | 37 | 1631 | 293 | 1940 | 202 |
| | U | 722 | 200 | 776 | 160 | 3071 | 327 | 2286 | 378 |
| | M | 812 | 122 | 846 | 210 | 2774 | 317 | 2976 | 309 |

Application of placed inorganic fertilizer on millet

A long-term experiment initiated in 1986 in Sadoré was continued within the project from 1998 to 2001. The objective of this trial was to measure the interactions between crop residues, manure and chemical fertilizers. It consists in a factorial arrangement of 13 treatments including continuous or rotation and intercropping of millet and cowpea either hand cultivated or planted on ridges made by animal traction. Each plot was divided in sub-plot with and without crop residue application, in turn subdivided in sub-sub-plots with and without nitrogen application. In 1998, manure, fertilizer and millet-cowpea rotation treatments explained 83% of the millet grain yield variations, ranging from 33 to 1829 kg ha$^{-1}$ and 73% of the variations of total plant mass that ranged between 889 and 6134 kg ha$^{-1}$(table 66). In 2001, the control treatment with no input and no return of millet stover yielded 146 kg ha$^{-1}$ whereas application of 13 kg ha$^{-1}$P and 30 kg N associated to a return of millet stover yielded 1866 kg ha$^{-1}$grain giving the scale of potential production increase with modest inputs.

**Table 66**: Effect of mineral fertilizers, crop residues, millet-cowpea rotation and tillage treatments on pearl millet grain and total production and phosphorus use efficiency, Sadoré, 1998.

| Treatment | Without CR | | | | With CR | | | |
|---|---|---|---|---|---|---|---|---|
| | TDM | | Grain | | TDM | | Grain | |
| | Yield | PUE | Yield | PUE | Yield | PUE | Yield | PUE |
| Control | 889 | | 33 | | 995 | | 61 | |
| 13 kg P/ha | 2704 | 140 | 633 | 46 | 4404 | 185 | 726 | 51 |
| 13 kg P/ha + ridge | 2675 | 137 | 448 | 32 | 3685 | 210 | 785 | 56 |
| 13 kg P/ha + rotation | 5306 | 340 | 1255 | 94 | 5392 | 338 | 1475 | 109 |
| 13 kg P/ha + ridge + rotation | 5223 | 333 | 1391 | 104 | 6249 | 404 | 1702 | 126 |
| SE | 407 | | 407 | | 407 | | 407 | |

Initiated in 1993 at Sadoré, a complementary trial was a complete factorial experiment with application of crop residue at 300, 900 and 2700 kg ha$^{-1}$, manure at 300, 900 and 2700 kg ha$^{-1}$, and mineral fertilizer with N at 0, 15, and 45 kg ha$^{-1}$, and P at 0, 6.5, and 13 kg ha$^{-1}$. In 1998, pearl millet grain yield was only 275 kg ha$^{-1}$ when only 300 kg ha$^{-1}$ of crop residue was applied while with the application of mineral fertilizers (13 kg P ha$^{-1}$ and 45 kg N ha$^{-1}$) combined with the application of 2.7 t of manure in the rotation cropping with cowpea, 2060 kgha$^{-1}$ of pearl millet grain was harvested. These results indicate that although the application of mineral fertilizers is an effective mean of increasing yields in arable farming systems, mineral fertilizers alone cannot sustain yields in the long-term. When mineral fertilizers are combined with other technologies such as crop residue, manure, rotations of cereals with legumes, soil ridging, productive and sustainable production systems can be obtained.

*On farm P sources and method of placement*

Initiated in 1998 along the bio-climatic gradient stretching from Gaya (the wet end) to Sadore (the dry end), on-farm fertilizer trials were conducted with 30 farmers within each of 4 villages (Sadore, Karabedji, Gobery and Gaya) strategically chosen along this gradient. The soils were acidic and inherently low in nutrients with ECEC of less than 1 cmol/kg for all the sites except Gaya where the organic carbon is slightly higher and an ECEC of 1.3 cmol/kg. (table 67) .Phosphorus sorption isotherm clearly indicated that most of the soils have very low capacity to fix P due to their sandy nature. As manure was used in most of the trials in combination with mineral fertilizer, a systematic chemical characterization of the manure used at the different sites was undertaken (table 68).Nitrogen and phosphorus levels in manure were very low and varied from 0.47% to 0.71% and the P levels varied from 0.08% to 0.38%.

**Table 67**: Annual precipitation (2001) and soil characteristics for selected villages.

| Sites | Rains (2001) mm | pH KCl | C.org (%) | P-Bray1 (mg/kg) | $Ca^{2+}$ Cmol/kg | ECEC Cmol/kg | $N_{min}$ (mg/kg) |
|---|---|---|---|---|---|---|---|
| Sadore | 460 | 4.3 | .12 | 2.0 | 0.3 | 1 | 3 |
| Banizoumbou | 344 | 4.4 | .12 | 1.5 | 0.4 | 0.8 | 5 |
| Karabedji | 378 | 4.2 | .16 | 1.9 | 0.2 | 0.8 | 4 |
| Goberi* | 450 | 4.1 | .16 | 1.7 | 0.2 | 0.8 | 2 |
| Gaya | 985 | 4.2 | .33 | 2.5 | 0.4 | 1.3 | 9 |

**Table 68:** Characterization for N, P, K and polyphenols of the organics materials used for the trial in each site.

| Sites | Manure origin | Total N (%) | Total P (%) | Total K (%) | Polyphenols (%) |
|---|---|---|---|---|---|
| Banizoumbou | Composite | 0.71 | 0.18 | 0.75 | 0.64 |
| Karabedji | Composite | 0.56 | 0.12 | 0.45 | 1.02 |
| Goberi | Composite | 0.47 | 0.08 | 0.23 | 0.64 |
| Gaya | Composite | 0.58 | 0.38 | 0.80 | 0.75 |

Several technologies were compared in these trials completely managed by the farmers, each comparing four treatments with no replicates. A first set of treatments included:

1) Control (millet with no inputs);
2) Hill placement of 4 kg P ha$^{-1}$;
3) Treatment 2 plus Tahoua Phosphate Rock (TPR) broadcast and incorporated at 13 kg P ha$^{-1}$;
4) Treatment 3 plus 2t ha$^{-1}$ of millet residues.

A second set of treatments included

1) Control (millet with no inputs);
2) Hill placement of 4 kg P ha$^{-1}$ plus TPR broadcast and incorporated at 13 kg P ha$^{-1}$;
3) TPR broadcast and incorporated at 13 kg P ha$^{-1}$ plus 2t ha$^{-1}$ cattle manure;

4) Treatment 2 plus 2t $ha^{-1}$ cattle manure.

In all these trials, crop yields were recorded and nutrient uptake determined.

In 1998, treatment explained 79% of grain yield variation at Karabedji, ranging from 205 to 827 kg $ha^{-1}$ (table 5). Moreover, the addition of 2.5 t $ha^{-1}$ of manure to phosphate amendments with or without N fertilizer increased yields. Grain yield of 919 kg $ha^{-1}$ obtained with phosphate amendments in Gaya was increased to 1268 when manure was added.

**Table 69.** Effect of different sources (SSP superphosphate, 15-15-15 NPK, TPR:Tahoua rock phosphate) and mode of application of phosphorus on pearl millet yield and Phosphorus Use Efficiency (PUE in kg per kg P applied) in Karabedji, 1998 rainy season

| P sources and method of application (selected treatments) | Grain | | Total dry matter | |
|---|---|---|---|---|
| | Yield (kg $ha^{-1}$) | PUE (kg $kg^{-1}$) | Yield (kg/$ha^{-1}$) | PUE (kg $kg^{-1}$) |
| Control | 281 | | 1726 | |
| SSP broadcast (13 kg P $ha^{-1}$ ) | 535 | 23 | 3726 | 154 |
| SSP broadcast + SSP hill placed (13 + 4 kg P $ha^{-1}$) | 743 | 27 | 5563 | 226 |
| SSP hill placed (4 kg P $ha^{-1}$ ) | 611 | 83 | 3774 | 514 |
| 15-15-15 broadcast (13 kg P $ha^{-1}$) | 660 | 29 | 4226 | 192 |
| 15-15-15 broadcast + hill placed (13 + 4 kg P $ha^{-1}$) | 1493 | 71 | 7677 | 350 |
| 15-15-15 (4 kg P $ha^{-1}$) | 690 | 102 | 4767 | 760 |
| TPR broadcast (13 kg P $ha^{-1}$) | 690 | 31 | 4135 | 185 |
| TPR broadcast + SSP HP (13 + 4 kg P $ha^{-1}$) | 663 | 22 | 4365 | 155 |
| TPR broadcast + 15-15-15 HP (13 + 4 kg P $ha^{-1}$) | 806 | 31 | 5061 | 196 |
| SE | 84 | | 194 | |

In 2000, for the fertilizer experiments along the bio-climatic gradient, in spite of agroecological differences in the study sites which are reflected in millet yields of control plots (with no inputs) which ranged from 152 kg grain $ha^{-1}$ in Goberi to 627 grain $ha^{-1}$ in Gaya, responses to fertilizer inputs followed the same trends (Tables 70, and 71). Grain and stalks yields increased along the ranking:

(Control) < (HP) < (HP + TPR) ~ (TPR + M) < (HP + TPR + CR) ~ ( HP + TPR + M)

**Table 70**. Effects of different fertilizer rates and crop residues on pearl millet grain and total biomass yield at Gaya, Goberi, Karabedji, and Sadoré* in the year 2000.

| Treatments | Villages/Yields (kg $ha^{-1}$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Gaya | | Goberi | | Karabedji | | Sadoré | | Sadoré (+N) | |
| | Grain | Total | Grain | Total | Grain | Total | Grain | Total | Grain | Total |
| T1 - Control | 613 | 2178 | 172 | 1229 | 218 | 2729 | 397 | 1505 | 418 | 1615 |
| T2 – HP | 964 | 3010 | 395 | 2417 | 501 | 4045 | 540 | 1945 | 541 | 2135 |
| T3 – HP + TPR | 1128 | 3416 | 560 | 3133 | 607 | 4607 | 581 | 2238 | 673 | 2435 |
| T4 – HP + TPR + CR | 1379 | 4027 | 717 | 3959 | 802 | 5872 | 740 | 2415 | 842 | 2847 |
| CV (%) | 10.86 | 5.15 | 15.16 | 9.34 | 9.35 | 9.31 | 14.64 | 8.42 | 14.64 | 8.42 |

* In Sadoré, the treatments also received 30 kg N $ha^{-1}$ as urea.

T1 = Control with no inputs

T2 = Hill placement (HP) of 6 g NPK 15-15-15 per hill, equivalent to 4kg P $ha^{-1}$

T3 = T2 + 13 kg P $ha^{-1}$ of Tahoua Phosphate Rock (TPR)

T4 = T3 + 2 tons $ha^{-1}$ of Crop Residue (CR).

In 2001 the amendment experiment repeated in Banizoumbou; Karabedji and Gobery, effect of N, P and manure on pearl millet yields were very high . In Banizoumbou, whereas P alone account for 60% of the total variation, nitrogen account for less than 5% in the total variation indicating that P is the most limiting factors at this site. Manure account for 8% in the total variation. The N and P fertilizer equivalency for 2t/ha of manure was 292 and 83% respectively (Table 72). In Karabedji, the optimum combination of organic and inorganic soil amendment gave yielded about 2 t/ha of millet grains whereas the control yield was 450 kg/ha. P and N fertilizer equivalency of manure ranging from 291 to 401% (Table 73 and 74).

**Table 71**. Effects of different fertilizer rates and manure on pearl millet grain and total biomass yield at Gaya, Goberi, Karabedji, and Sadoré* in the year 2000.

| Treatments | Villages/Yields (kg $ha^{-1}$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Gaya | | Goberi | | Karabedji | | Sadoré | | Sadoré (+N) | |
| | Grain | Total | Grain | Total | Grain | Total | Grain | Total | Grain | Total |
| T1 – Control | 627 | 2305 | 217 | 1343 | 229 | 2598 | 483 | 1659 | 532 | 1822 |
| T2 - TPR + HP | 1105 | 3406 | 675 | 3450 | 508 | 3859 | 656 | 2142 | 670 | 2328 |
| T3 - TPR + M | 1207 | 3724 | 613 | 3010 | 492 | 3799 | 779 | 2641 | 801 | 2775 |
| T4 - TPR + HP + M | 1410 | 4258 | 939 | 4758 | 648 | 4806 | 828 | 2954 | 984 | 3366 |
| CV (%) | 9.35 | 5.47 | 26.68 | 10.62 | 13.08 | 12.32 | 8.57 | 4.36 | 8.57 | 4.36 |

* In Sadoré, the treatments also received 30 kg N $ha^{-1}$ as urea.
T1 = Control with no inputs
T2 = 13 kg P $ha^{-1}$ of Tahoua Phosphate Rock (TPR) plus hill placement (HP) of 6 g NPK 15-15-15
per hill, equivalent to 4kg P $ha^{-1}$
T3 = 13 kg P $ha^{-1}$ of Tahoua Phosphate Rock (TPR) plus 2 t $ha^{-1}$ of manure (M)
T4 = T2 plus 2 t $ha^{-1}$ of manure (M)

**Table 72**: Analysis of variance expressed as percentage of total sum of squares for pearl millet grain and total dry matter yield, Banizoumbou, Niger 2001 rainy season.

| | Grain | | TDM | |
|---|---|---|---|---|
| Replication | 8.02 | ** | 1.41 | * |
| Phosphorus (P) | 61.75 | ** | 63.25 | ** |
| Manure (M) | 8.28 | ** | 6.36 | ** |
| P*M | 3.86 | ** | 0.46 | ns |
| Nitrogen (N) | 3.16 | ** | 5.84 | ** |
| P*N | 0.29 | ns | 1.72 | * |
| M*N | 2.37 | ** | 1.31 | ns |
| P*M*N | 0.93 | ns | 5.14 | ** |
| Error | 11.34 | ns | 14.50 | ns |
| Total | 100.00 | | 100.00 | |

** High significant *significant ns non significant

**Table 73:** Fertilizers equivalency of manure at Banizoumbou, Niger, 2001 cropping season

| | Banizoumbou | | Karabedji | |
|---|---|---|---|---|
| Parameters | Grain (kg/ha) | Total dry matter (kg/ha) | Grain (kg/ha) | Total dry matter (kg/ha) |
| Absolute control | 290 | 1275 | 171 | 810 |
| Control for N | 1210 | 4550 | 812 | 3280 |
| Control for P | 635 | 2280 | 356 | 2062 |
| % N in manure | 0.71 | 0.71 | 0.56 | 0.56 |
| % P in manure | 0.18 | 0.18 | 0.12 | 0.12 |
| Yield at 2t/ha of manure without N | 1530 | 5450 | 1114 | 3991 |
| Yield at 4t/ha of manure without N | 1695 | 4855 | 1432 | 5023 |
| Yield at 2t/ha of manure without P | 810 | 2910 | 708 | 3183 |
| Yield at 4t/ha of manure without P | 1070 | 3625 | 1114 | 4060 |
| Equivalent N for 2t/ha of manure | 41.53 | 38.90 | 44.5 | 45 |
| Equivalent N for 4t/ha of manure | * | 21.1 | * | * |
| Equivalent P for 2t/ha of manure | 3 | 2.71 | 7 | 9.28 |
| Equivalent P for 4t/ha of manure | 7.5 | 5.57 | 17.5 | 19 |
| N fertilizer equivalency at 2t/ha of manure | 292 | 273 | 397 | 401 |
| N fertilizer equivalency at 4t/ha of manure | * | 74 | * | * |
| P fertilizer equivalency at 2t/ha of manure | 83 | 75 | 291 | 386 |
| P fertilizer equivalency at 4t/ha of manure | 104.1 | 77 | 364 | 395 |

In the comparison of broadcast and hill placement of P associated to manure carried out in Karabedji, hill placement of manure performed better than broadcasting and with no application of P fertilizer, broadcasting 3 t/ha of manure resulted in 700 kg/ha millet grain whereas the point placement of the same quantity of manure gave about 1000 kg/ha (table 74)

**Table 74:** Fertilizers equivalency of manure applied in broadcast and hill placement methods at Karabedji, Niger, 2001 cropping season

| Parameters | Millet grain (kg/ha) | Total plant dry matter (kg/ha) |
|---|---|---|
| Control | 97 | 348 |
| % P in manure | 0.12 | 0.12 |
| Yield at 3t/ha of manure (broadcast) | 722 | 1209 |
| Yield at 3t/ha of manure (hill placed) | 986 | 1585 |
| Yield at 6t/ha of manure (broadcast) | 1069 | 1737 |
| Yield at 6t/ha of manure (hill placed) | 1027 | 1738 |
| Equivalent P of manure 3t (broadcast) | 5.8 | 5.17 |
| Equivalent P of manure 3t (hill placed) | 8.87 | 8.44 |
| Equivalent P of manure 6t (broadcast) | 9.86 | 10.81 |
| Equivalent P of manure 6t (hill placed) | 9 | 10.81 |
| P fertilizer equivalent of manure 3t (broadcast) | 161 | 143 |
| P fertilizer equivalent of manure 3t (hill placed) | 246 | 234 |
| P fertilizer equivalent of manure 6t (broadcast) | 137 | 150 |
| P fertilizer equivalent of manure 6t (hill placed) | 125 | 150 |

In addition to these on-farm trials, a total of 580 famer's managed demonstration trials of hill placed application of mineral fertilizer (NPK 15-15-15 or DAP) at a rate of 4 kg P ha$^{-1}$ (9 kg $P_2O_5$ ha$^{-1}$) in fields with different history of organic amendments have been carried out in collaboration with the FAO Projet Intrants the regions of Niamey, Maradi and Zinder. The objective of these demonstration trials was to evaluate *in-situ* the agronomical and economical performance of hill placed application of different formulation of mineral fertilizer associated or not to organic amendments.

During the last two rainy season, 120 (2000) and 140 (2001) demonstrations were located within the Tillabéry benchmark site (table 75). Fifty rain gauges have been installed throughout the landscape to monitor and record individual rainfall events and an automated Campbell CR10 was installed in May 2000 and running since in the village of Katanga. Hourly and daily weather data (temperature, water vapor pressure, solar radiation, wind speed and direction) have been recorded since the installation of the station and allowed the calculation of daily potential evapotranspiration according the modified Penman equation. In 2001 each demonstration consisted in 3 plots with the following treatment (control, application of NPK 15-15-15 at a rate of 6 g fertilizer per hill, and application of DAP at a rate of 2 g fertilizer per hill at sowing). In 2002, an additional treatment consisting of the application of 2 g DAP per hill at sowing and 1 g urea at tillering was added. Plots were contiguous and had dimension of 20x30m. None of the 2001 demonstration sites were reused for 2002 demonstrations. In order to gain more information on the interaction between organic and inorganic fertilizer, a stratification was made on previous land use to approximately one third of the demonstration on fields which did not received manure, one third on fields which received transported manure and one third on fields which received manure through corralling. In 2002, four strata were used to split the corralled fields into two strata according the time of corralling: corralled in dry season 2000-2001 or corralled in dry season 1999-2000. The data measured on each demonstration were: date of planting and harvesting, planting density, intercropping or not, incidence of Striga (parasitic plant) in the fields, presence of bushes, grain yield estimated from bundle weighting at harvest and grain/bundle ratio obtained on a 2 kg millet head sub-sampled per plot.

The cumulative rainfall was below average for both season with an average of 410 mm in 2000 and 377 mm in 2001. Despite a lower rainfall, the distribution throughout the season was better in 2001, the 2000 season suffered from a long dry spell lasting from mid August to mid September coinciding with millet flowering and maturing. The minimum cumulative rainfall recorded was 251 mm in 2000 and 235 mm in 2001. The maximum cumulative rainfall was in 664 mm in 2000 and 503 mm in 2001. This shows the wide range of water balance conditions we can obtain in testing the technologies at the landscape scale. Yields as presented in table 1 showed an increase with the application of mineral fertilizer for both years under all combinations of mineral and organic fertilizer. The analysis of variance indicates no significant differences in grain yield ($p < 0.01$) between the application of DAP and NPK. There are, as expected, large yield differences across organic fertilization strata. Grain yields are overall much lower than the national average for millet yields due to the unfavorable rainy season and the soil characteristic.

In 2000, 32.4% of the variance in grain yield was explained by a linear combination of fertilizer treatment, organic manuring practices, planting density, geomorphological class. The variate ‘cumulative rainfall’ was not significant in explaining grain yield. In 2001, 38.2% of the variance in grain yield was explained by a linear combination of fertilizer treatment, organic manuring practices, planting density, Striga infestation level, village. The factor

**Table 75.** Grain yield for Fakara demonstrations in 2000 and 2001.

| | Grain yield (kg ha-1) | | | |
|---|---|---|---|---|
| | DAP | DAP + Urea | NPK | Control |
| | | Rainy season 2000 | | |
| No manure | 275 | na | 250 | 157 |
| Transported manure | 375 | na | 370 | 236 |
| Corralling in 2000 | 613 | na | 507 | 440 |
| | | Rainy season 2001 | | |
| No manure | 173 | 213 | 180 | 119 |
| Transported manure | 303 | 318 | 292 | 258 |
| Corralling in2000 | 300 | 325 | 324 | 261 |
| Corralling in 2001 | 394 | 415 | 378 | 350 |

village is highly significant and explain a large fraction of the grain yield variance as they account for spatial difference in rainfall patterns, implicitly embedding water balance and water stress differences throughout the season.

- To study more in depth the combined effects of micro-doses of placed fertilizer (DAP or NPK) with the residual effect of organic amendments by corralling livestock, a series of on-station and on-farm trials were conducted in 2001 in collaboration between IFDC-ILRI-ICRISAT. At Sadoré, fields amended by corralling cattle, sheep and goats during the rainy seasons of 1998, 1999 and 2000 and cropped since in millet received 0, 2, 4, 8 or 12 kg $P_2O_5$ $ha^{-1}$ as placed NPK 15-15-15 just prior to the rainy season. They were cropped in millet in order to measure the combined effect of manure and inorganic fertilizer as a function of the interval between the two amendments (table 75b). On a nearby plot the response curves to micro-doses of NPK and DAP fertilizers were established on millet (Table 75c). The comparison of cattle versus sheep-goats corralling indicated that at equal level of feces applied grain and stover yields were equal or higher with cattle manure in the two first years, and higher with small ruminants in the third year following application. Slow decomposition rate of goat/sheep manure relative to that of cattle may have contributed to the reverse trend (Hiernaux et al. 1998; Somda, 1994). Yields in the absolute control plots (no fertilizer and no manure) were generally lower than their counterparts with only manure, emphasizing the impoverished nature of the soils, hence, the need for some manure. Yields response to 6t DM manure application declined over years, the two- and one-year residual effects are more efficient than the three-year, suggesting that this type of corralling may be required at the end of every two cropping seasons in order to sustain crop productivity. When combined over years, millet performance obtained on plots manured with cattle or goat/sheep where nearly the similar (Table 1 and 2). However, millet grain yield was higher on the plots manured with goat than cattle dropping in the two-year residual plots. But the results were the reverse in the one-year residual plots and almost identical in the plots freshly manured and fertilized. Differences in the quality of goat/sheep and cattle manure may have contributed to this trend (waiting for manure chemical analysis). Millet grain and stover yields increased steadily up to highest level of fertilizer P applied while yields in the absolute control were generally lower, reflecting the impoverished nature of the soils.

**Table 75b. Combined effect of goat/sheep or cattle corraled manure and DAP fertilizer on millet grain yield (kg ha$^{-1}$)**

| Year | | 1998 | | 1999 | | 2000 | | Mean | |
|---|---|---|---|---|---|---|---|---|---|
| Manure | | Cattle | Goat | Cattle | Goat | Cattle | Goat | Cattle | Goat |
| P rate[1)] | | 258 | 334 | 315 | 286 | 847 | 746 | 473 | 455 |
| | 2 | 318 | 379 | 353 | 315 | 602 | 581 | 424 | 425 |
| | 4 | 335 | 436 | 416 | 373 | 1179 | 1100 | 643 | 636 |
| | 8 | 352 | 508 | 443 | 404 | 1233 | 1224 | 676 | 712 |
| | 12 | 477 | 538 | 557 | 454 | 1334 | 1301 | 789 | 764 |
| Mean | | 348 | 439 | 417 | 366 | 1039 | 990 | 601 | 599 |
| SE | | | | | | | | 82 | |
| CV (%) | | | | | | | | 24 | |
| Source | | | | | | | | Probability | |
| Type of manure | | | | | | | | NS | |
| Year | | | | | | | | ** | |
| P rate | | | | | | | | *** | |

1) $P_2O_5$ kg ha$^{-1}$; ** and *** indicate signifiance at the 0.01 and 0.001 levels; NS not significant

Responses curves established that 8 kg $P_2O_5$ ha$^{-1}$ applied the third year after 6t DM ha$^{-1}$ animal was the optimum for stover production to satisfy livestock and other domestic needs (Fig. 6) while no consistent stover yield response was observed in the two- and one-year residual plots. P source was not a significant factor (Table 75c). Millet response to the two different sources of fertilizer P was nearly similar, though theoretically the fertilizer N rate applied by using DAP may have been higher than using NPK. The higher N rate applied when using DAP did not show any superior effect on millet performance as compared to NPK, indicating the more limiting effect of P (as compared to N) for the yield building by millet. P rate was a significant factor (Table 75c). Millet yield responded significantly to microdose P fertilizer from both sources up to the highest rate. Millet yield response to increasing rate of fertilizer P from both sources was nearly the same. The yield increases became negligible at the highest fertilizer P rates.The harvest index was influenced neither by P source nor by P rate. Indeed, the increasing rate of fertilizer P from both sources did not show any effect on the harvest index. P source did not show any visible effect on the agronomic efficiency of fertilizer P. The agronomic efficiency of fertilizer P seems however to decrease with increasing P rates. These results are comparable to those in Table 4, confirming the assumption of the increased fertilizer P loss (decreased efficiency of fertilizer P) when applying higher fertilizer P rates.

**Table 75c. Millet yield response to microdose fertilizer P from DAP or NPK**

| | Grain Yield | | Stover Yield | | Harvest Index | | Agron. Efficiency | |
|---|---|---|---|---|---|---|---|---|
| | Kg ha | | Kg ha | | % | | Kg kg | |
| Fertiliser | NPK | DAP | NPK | DAP | NPK | DAP | NPK | DAP |
| P rate | | | | | | | | |
| 0 | 651 | 651 | 1890 | 1890 | 26 | 26 | - | - |
| 2 | 842 | 845 | 2228 | 2120 | 28 | 29 | 215 | 218 |
| 4 | 950 | 957 | 2453 | 2385 | 28 | 29 | 168 | 172 |
| 8 | 1100 | 1131 | 2863 | 2810 | 28 | 29 | 126 | 135 |
| 12 | 1226 | 1161 | 2948 | 2940 | 29 | 28 | 108 | 96 |
| Mean | 954 | 949 | 2476 | 2429 | 28 | 28 | | |
| SE | 55 | | 86 | | 1 | | | |
| CV(%) | 12 | | 7 | | 8 | | | |
| Source | | | Probability | | | | | |
| Fertiliser | NS | | NS | | NS | | | |
| Prate | *** | | *** | | NS | | | |
| CV(%) | 12 | | 7 | | 8 | | | |

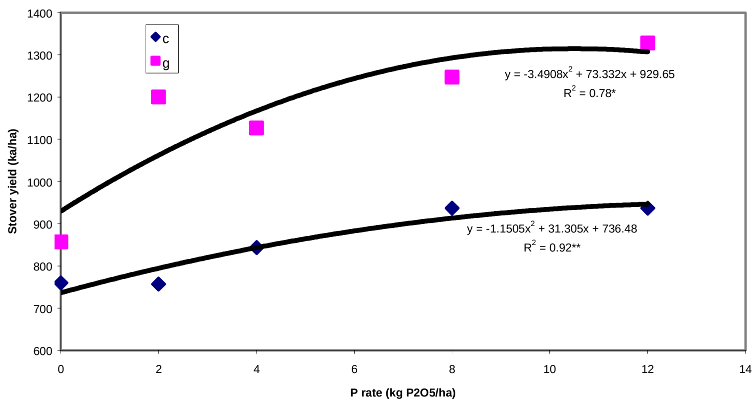



**Fig. 6. Millet stover response to microdose DAP fertilizer under three-year residual effect of manure**

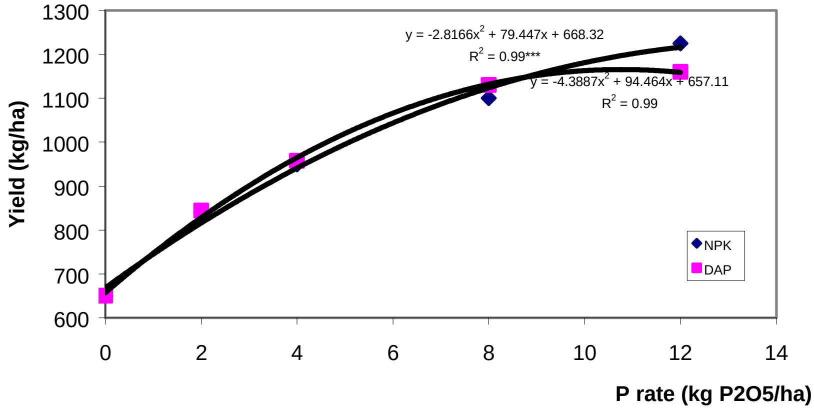



**Fig 7. Millet response to microdose P fertilizer**

Promote cowpea to improved soil fertility maintenance, crop productivity and livestock feed quality

Along the bio-climatic gradient stretching from Gaya (the wet end) to Sadore (the dry end), on-farm fertilizer trials were conducted with 30 farmers within each of 4 villages (Sadore, Karabedji, Gobery and Gaya) strategically chosen along this gradient. In the same set of villages, farmer-managed on-farm trials were established in 1999 to test the “legumes first” concept, i.e. giving the same priority to legumes as cereals in the cropping systems. These on-farm trials were continued till 2001. The tests included:

1) Control (millet intercropped with cowpea with no inputs);
2) TPR applied at 13 kg P $ha^{-1}$ and hill placement of 4 kg P $ha^{-1}$ to sole crop pearl millet;
3) Treatment 2 applied to pearl millet intercropped with cowpea;
4) Treatment 3, with plot split into two with half planted to pure cowpea and half planted to pure pearl millet with rotation in the second year.

As Table 76 shows, the yields of millet inter-cropped with cowpea which received 6g hill placed NPK and 13 kg of broadcast rock phosphate (TPR) were similar to the yields obtained with pure millet which received the same inputs, while the yield of millet cropped in rotation with cowpea and with same inputs were equivalent to yields obtained in adding 2t $ha^{-1}$ of either manure or millet residues.

**Table 76.** Effects of different fertilizer rates, intercropping IC and rotation RT with cowpea on pearl millet grain and total biomass yield at Gaya, Goberi, Karabedji, and Sadoré* in the year 2000.

| Treatments | Villages/Yields (kg $ha^{-1}$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Gaya | | Goberi | | Karabedji | | Sadoré | | Sadoré (+N) | |
| | Grain | Total | Grain | Total | Grain | Total | Grain | Total | Grain | Total |
| T1 - Control | 506 | 2065 | 152 | 1151 | 164 | 2467 | 551 | 1614 | 479 | 1782 |
| T2 - HP + TPR | 968 | 2995 | 550 | 2972 | 433 | 3862 | 619 | 2093 | 780 | 2358 |
| T3 - HP + TPR + IC | 1121 | 3320 | 614 | 2966 | 435 | 3959 | 418 | 1664 | 560 | 1898 |
| T4 - HP + TPR + RT | 1373 | 3966 | 840 | 4092 | 736 | 6265 | 1088 | 2954 | 873 | 3097 |
| CV (%) | 13.60 | 9.17 | 20.47 | 11.71 | 7.73 | 14.24 | 28.68 | 5.55 | 28.68 | 5.55 |

* In Sadoré, the treatments also received 30 kg N $ha^{-1}$ as urea.
T1 = Control (millet intercropped with cowpea with no inputs);
T2 = Hill placement of 4 kg P $ha^{-1}$ plus TPR applied at 13 kg P $ha^{-1}$ to sole crop pearl millet;
T3 = Treatment 2 applied to pearl millet intercropped with cowpea;
T4 = Treatment 3, with plot split into two with half planted to pure cowpea and half planted to pure pearl millet with rotation in the second year.

Interactions between inorganic N and P amendments with manure were studied in a farmer managed trial repeated in three villages: Banizoumbou; Karabedji and Gobery. The design is factorial with manure (0, 2 and 4 t/ha), nitrogen (0, 30 and 60 kg N/ha) and phosphorus (0, 6.5 and 13 kg P/ha). The results are used to assess the fertilizer equivalency of manure for N and P.

In addition, a complete factorial experiment was carried out in Karabedji with three levels of manure (0, 3, 6t/ha) three level of P (0, 6.5 and 13 kg/P ha) using two methods of application (broadcast and hill placement) to assess the effect of combined manure and P amendments with different model of placement on both millet and cowpea crops.
Cowpea  showed the same response. P fertilizer equivalency of manure was 161% with broadcast application and 246% with hill placement for millet grain (Table 77).Results on cowpea crop highlight the advantage to combine organic and inorganic plant nutrients for the poorly buffered soils of the Sahel.

**Table 77**: Optimum combination of plant for cowpea fodder (kg/ha) trial in Karabedji, 2001

| Treatments | Cowpea haulms (kg DM $ha^{-1}$) |
|---|---|
| 1 Absolute Control | 1875 |
| 2 30 kg N $ha^{-1}$ | 2531 |
| 3 12 kg P $ha^{-1}$ | 3781 |
| 4 8 tons manure + 30 kg N $ha^{-1}$ | 5718 |
| 5 6T manure + 3kg P + 30 kg N | 4843 |
| 6 4T manure + 6 kg P + 30 kg N | 4656 |
| 7 2T manure + 8 kg P + 30 kg N | 4281 |
| 8 12 kg P + 30 kg N | 5000 |
| SE | 204 |
| CV | 14% |

In a separate on-farm trial carried out at Banizoumbou, ways to maintain or increase millet productivity in millet-cowpea intercropping systems were tested by implementing and annual rotation between the millet and cowpea rows so as to make the millet crop benefit from the residual effects of the inputs applied to the cowpea rows in the previous year. The design was randomized split-split-plot design with main plot being SSP hill-placed in cowpea rows, subplot being the broadcast of crop residues and sub-sub plot the level of crop residue (0.6, 1.2 t $ha^{-1}$). Millet was sown with the first rain exceeding 15 mm and cowpea 3 weeks thereafter. Millet and cowpea were sown in alternate rows at a density of 6666 hills/ha. SSP, ridging and banded residue were applied strictly in the cowpea row. Response variables included millet and cowpea yields and nutrient uptake by the crops.

in 1999, initial results of the on-farm trial on cowpea-millet associated crop demonstrate the detrimental effect of placed NPK fertilizer on millet and cowpea emergence despite a sowing rain exceeding 25mm. However, in spite of the poor emergence, millet growth of surviving hills was significantly improved by the addition of hill-placed fertilizer, resulting in a doubling of average millet plant height at the end of the growing season. In all these trials, crop yields were recorded and nutrient uptake determined. In 2000, as a result a drought during the month of August, average millet yields were 26% lower than in 1999. Fertilizer effectiveness was also much reduced. Whereas hill-placement of NPK fertilizer resulted in a three-fold increase in millet yields in 1999 (from 136 to 421 kg grain $ha^{-1}$ (l.s.d. = 54)), it increased grain yields by only 60% in 2000 (from 159 to 253 kg $ha^{-1}$ (l.s.d. = 146)). In 2000, cowpea productivity was extremely low approximately one tenth the yield in 1999. This was attributed to low average hill survival rate (48%) and lower production of individual hills - from 38 g fodder $hill^{-1}$ in 1999 to 5 g fodder $hill^{-1}$ in 2000. Average cowpea fodder production was increased by 64% following hill-placed fertilizer application (from 13 to 21 kg $ha^{-1}$), but this effect was not significant (l.s.d. = 10.5). This is in contrast to 1999 when hill-placement of fertilizer resulted in a significant decrease in cowpea productivity. The difference between the two years may be the result of a change in fertilizer placement. Whereas in 1999 the fertilizer was placed at sowing time together with the seeds, in 2000 the fertilizer was placed next to the hills at the time of the next rain following sowing. This latter procedure may have resulted in a reduced risk of seed burning by the fertilizer. In 2000, there was a significant interaction between residue management and residue rate of application (P = 0.014). Doubling of the mulching rate from 600 to 1200 kg $ha^{-1}$ resulted in a 54% increase in millet grain yield in those plots where residue was broadcast at the start of the rainy season. When applied at the start of the previous dry season, an increase in mulching rate increased millet grain production by only 13%. However, a 27% decrease in millet grain yield was observed on the plots where banded residue had been buried in ridges.

The lesser effectiveness of the high mulching rate on the plots where mulching was carried out at the start of the dry season may be due to partial uptake of the fodder by free-ranging livestock during the course of the dry season. The decrease in millet grain yield with increasing mulching rate on the buried banded residue plots was linked to a significant decrease in the number of tillers as well as a decrease in the thousand grain weight. There was no impact of residue management or mulching rate on cowpea productivity in 2000.

Due to the incorrect implementation of certain treatments since 2000, the experiment could not be analyzed based on the original design in 2001. In particular, the effect of the timing of crop residue application could no longer be evaluated. In addition, the rates of crop residue application presently differ between the ridged treatment (0.6 and 1.2 t $ha^{-1}$) and the broadcast mulch (1.2 and 2.4 t $ha^{-1}$). An unmulched 'control' plot had to be considered in the present analysis.

In 2001, millet yielded 239 kg grain $ha^{-1}$, 14% lower than in 1999 but 16% higher than in 2000. Average cowpea fodder yield (78 kg $ha^{-1}$) was almost 5 times higher than in 2000 but still 60% lower than in 1999. There was a significant response of millet grain yield to hill-placed fertilizer application ($P<0.01$). Millet grain yield was increased by 150% following fertilizer application, which was intermediate between 1999 (210% yield increase) and 2000 (60% yield increase). Fertilizer application did not impact plant survival but significantly increased all other yield components: +89% for number of head bearing tillers per hill, +32% for number of grains per head, and + 9% for the single grain weight. The impact of fertilizer was therefore strongest on the vegetative development of millet (tillering), but also impacted the grain forming and filling stages. The impact of fertilization on millet straw yield was similar as for grain yield. There was no effect of fertilization on cowpea grain or fodder yields. Broadcast residue application increased millet grain and straw yield on average by 91 and 587 kg $ha^{-1}$, respectively, compared to the unmulched control plots (l.s.d. = 66 and 269 kg $ha^{-1}$). For grain yield, this was the result of improved millet stands at harvest by 7% (l.s.d. = 6%), increased tillering from 1.85 to 2.53 tillers per hill as compared to the control plots (l.s.d. = 0.5), and an increase in the number of grains per head by 16%. There was no effect of the mulch application rate on grain yield but doubling of the mulching rate from 1250 to 2500 kg $ha^{-1}$ resulted in a straw yield increase of 23% compared to the unmulched plots. Mulching did not effect cowpea stands nor fodder yields in 2001.

The burial of crop residue (CR) in ridges did not have a significant residual effect on millet grain or straw yields in 2001, irrespective of the residue application rate (625 or 1250 kg $ha^{-1}$). It also did not have a significant impact on cowpea fodder yields compared to the control plots, but grain yields were increased by 56% on average. There was no statistically significant effect of fertilization on soil chemical properties in 2001. This may be due to the very low application rate of the hill-placed fertilizer but also to the fact that hill placement affects only about 1.5% of the soil surface area.

Compared to the unmulched control, there was a small but significant increase in soil pH (KCl) of 0.06 units following mulching, whose impact increased with the application rate (l.s.d. = 0.038). This resulted in a decrease of Al saturation of the exchange complex from 26% on the control plots to 21% on the plots mulched with 1.25 t $ha^{-1}$ of CR and to 12% on plots mulched with 2.5 t $ha^{-1}$ of CR (l.s.d. = 5%). Mulching also significantly increased organic carbon content by 0.006% on average compared to the control plots ($P<0.01$). Similarly, exchangeable $K^+$ content was increased from 0.071 $cmol_+ kg^{-1}$ in the control plots to 0.085 and 0.097 $cmol_+ kg^{-1}$ in the plots mulched with 1.25 and 2.5 t $ha^{-1}$ of CR, respectively (l.s.d. = 0.008). The burial of CR in ridges significantly increased soil pH (KCl) by 0.1 unit in the cowpea row of fertilized plots only (l.s.d. = 0.08), irrespective of the CR application rate. There was no residual effect on soil pH of the burial of CR in ridges in the millet row. Al saturation decreased from 25% in the millet row to 16% in the cowpea row of ridged plots (l.s.d. = 7%). Compared to the control plots, exchangeable $K^+$ content in the cowpea row was increased by 0.018 and 0.036 $cmol_+ kg^{-1}$ following the burial of 0.625 and 1.2 t $ha^{-1}$ of CR in ridges, respectively (l.s.d. = 0.009). There was no residual effect of this treatment on exchangeable $K^+$ content in the millet row.

Given the low inherent fertility of the sandy aeolian soils of western Niger and the low impact of the treatments on soil chemical quality, yields remained low overall in 2001. For the third year in a row, hill-placement of NPK (15-15-15) fertilizer did not have a significant positive impact on cowpea productivity. It helped boost millet yields, however, resulting in millet straw yields that would nevertheless barely balance a mulch input of 1250 kg $ha^{-1}$. Under the low input conditions evaluated in the present trial, mulching would therefore not constitute a viable option.

### 3.5. Discussion and ex-post economic assessments

Energetic, proteic and mineral supplementation for sheep fattening

The ex-post assessment of the benefit and margin of return on investment in sheep fattening was calculated with or without reference to a interest rate to the capital invested of 8% (table 78). The purchase prices of the sheep were very similar, because all sheep were bought on the same market. The cost of the millet bran was making about half of the feed cost.

**Table 78:** Net benefit and economic returns of sheep fattening with different quantities of cowpea haulms (Nadara, Tahoua, 2002)

| Cowpea haulms in diet (g $d^{-1}$) | 0 | 200 | 400 | 600 |
|---|---|---|---|---|
| Sale price ( cfa) | 30572 ±2503 | 31182 ±1910 | 32182 ±2167 | 32182 ±3040 |
| manure price | 351 | 351 | 351 | 351 |
| **Gross product** | **4016 ±2581** | **5777 ±1950** | **7000 ±1473** | **7273 ±2422** |
| * cowpea haulms (cfa) | 0 | 405.6 | 808.6 | 1214.2 |
| * millet bran (cfa) | 1585.7 | 1588.8 | 1582.9 | 1573.4 |
| * sorghum stover (cfa) | 861.7 | 637.7 | 628.1 | 638.0 |
| **Total cost of feed** | **2447** | **2632** | **3020** | **3426** |
| * antiparasite | 190 | 190 | 190 | 190 |
| * vaccination | 50 | 50 | 50 | 50 |
| * treatments | 75 | 400 | 37.5 | 400 |
| **Total veterinary costs** | **315** | **640** | **277.5** | **640** |
| * equipment depreciation (troughs) | 158 | 158 | 158 | 158 |
| * barn depreciation | 240 | 240 | 240 | 240 |
| **Total depreciations** | **398** | **398** | **398** | **398** |
| Labour | 1980 | 1980 | 1980 | 1980 |
| **Total costs** | **3160** | **3670** | **3695** | **4464** |
| **Net benefit** | **1207** | **2458** | **3656** | **3160** |
| **Rate of return (%)** | **4** | **8** | **12** | **9** |
| **Marginal rate of return (%)** | **Ref** | **245** | **458** | **150** |
| Invested capital | 31696 | 30055 | 30757 | 30653 |
| Capital Interest (rate of 8%) | 2536 | 2404 | 2461 | 2452 |
| Net benefit | -1329 | 54 | 1195 | 708 |
| **Rate of return with interest rate (%)** | **-4** | **0** | **4** | **2** |
| **Marginal rate of return with interest rate (%)** | **Ref** | **366** | **549** | **167** |

Despite non significant differences in sheep weight gains with increased quantity of cowpea offered, the increase in digestibility efficacy due to the enhancement of the digestible proteins of the diet increased the net benefit from negative when no cowpea was offered to a maximum for 400g of cowpea per day. Return to the capital invested were quite low even if interest rates of capital invested were not considered (table 78) but marginal rate of return of the investment made in cowpea haulms were largely positive with a maximum reached at 400 g $d^{-1}$. This confirms that the inclusion of cowpea haulms to the fattening diet based on sorghum stover and 400 g $d^{-1}$millet bran is beneficiary with an optimum at a relatively low level.

Strategic supplementation at the end of the dry season of reproductive cows

The main product of the reproductive cows that are not milked are the calves. The changes in weight of the female cow mainly reflect seasonal fluctuation in forage availability and quality, combined with physiological status of the cow. The economic assessment of the use of strategic supplements at the end of the dry season was thus done based on the number of calves produced per adult cow per year, multiplied by the average weight of a six months old calf. As the weaning does not occur before 12 months, the average quantity of meat produced through the growth of calves till weaning is added to the production of calves. The cost of supplementation including labour is subtracted from this product to assess the annual benefit per cow (table 18b). Benefits increased only at the lower rate of supplementation and only by 1600 CFA per cow so that the rate of return of the investment in supplementing the animal was only 37%. Thus, only if such strategic supplementation has an impact on the career of cow (age at culling or death, and number of calves over the whole career) or on milk production that it may be more beneficiary and really pay for the supplements.

**Table 78b:** Net benfit and economic return of supplement feeding in the dry season with millet bran and super-phosphate (2g or 4 gper cow per day in proportion with millet bran) (Gourou Yéna and Katanga, 1999-2002)

| Annual product and cost per reproductive cow, Prices are expressed in CFA $cow^{-1}$ $yr^{-1}$ | Feed supplement levels (millet bran g $d^{-1}$) 0,00 | 360,00 | 720,00 |
|---|---|---|---|
| Average calve produced by cow (kg $cow^{-1}$ $yr^{-1}$) | 15,65 | 20,35 | 20,45 |
| Average calve raised to weaning (kg $cow^{-1}$ $yr^{-1}$) | 4,68 | 6,07 | 6,10 |
| Sale price of average calf produced (1000 CFA $kg^{-1}$) | 15650,00 | 20350,00 | 20450,00 |
| Sale price of average calf raised to weaning (850 $kg^{-1}$) | 3978,00 | 5159,50 | 5185,00 |
| **Gross product** | **19628,00** | **25509,50** | **25635,00** |
| * cost of millet bran (105d) | 0,00 | 3780,00 | 7560,00 |
| * cost of phosphate (105d) | 0,00 | 50,00 | 100,00 |
| * labour to distribute supplements (105d) | 0,00 | 450,00 | 450,00 |
| **Total cost of supplementation** (105d) | **0,00** | **4280,00** | **8110,00** |
| Net benefit | 19628,00 | 21229,50 | 17525,00 |
| **Rate of return with interest rate (%)** | ref | 37,42 | D |

Improved corralling of livestock to better manage soil fertility for millet crop

The ex-post assessment of the benefit and margin of return on labour investment in livestock corralling practices was calculated separately for a cattle herd and for a sheep-goat mix. The calculation is done for a farm in which 15 ha are cropped in millet, with or without resident livestock either 12 cattle of 24 sheep plus 24 goats (48 small ruminants of 25 kg live weight

**Table 78c**. Net benefit and economic return of five methods to apply manure by corralling either cattle or a mix of sheep and goats on fields cropped in millet compared to cropping millet without manure application. The five methods differ by the rate of application at the corralling spot for the same total amount of manure produced during the year cycle.

| **Treatments (rate of manure t ha$^{-1}$)** | **0** | **2** | **4** | **6** | **10** | **14** |
|---|---|---|---|---|---|---|
| area manured in 1 year (ha) | 0 | 3.5 | 1.7 | 1.2 | 0.7 | 0.5 |
| area manured in 4 years (ha) | 0 | 14.0 | 7.0 | 4.7 | 2.8 | 2.0 |
| area unmanured over 15ha (ha) | 15 | 1.0 | 8.0 | 10.3 | 12.2 | 13.0 |
| Labour to remove tethering posts(adult day) | | | | | | |
| Cattle | 0 | 30.2 | 15.1 | 10.0 | 6.0 | 4.30 |
| sheep-goats | 0 | 60.8 | 30.4 | 20.3 | 12.2 | 8.7 |
| Labour to handle animal corralled (adult day) | | | | | | |
| cattle | 0 | 45.6 | 45.6 | 45.6 | 45.6 | 45.6 |
| sheep-goats | 0 | 91.2 | 91.2 | 91.2 | 91.2 | 91.2 |
| total corralling labour (adult day) | | | | | | |
| cattle | 0 | 75.8 | 60.7 | 55.7 | 51.7 | 49.9 |
| sheep-goats | 0 | 152.1 | 121.7 | 111.5 | 103.4 | 99.9 |
| Weeding labour (adult day) | 90 | 76.0 | 83.2 | 85.3 | 87.2 | 88.0 |
| harvest labour (adult day) | 48.45 | 75.8 | 67.0 | 65.2 | 63.4 | 63.1 |
| total labour (adult day) | | | | | | |
| cattle | 138.45 | 227.5 | 210.7 | 206.2 | 202.3 | 201.1 |
| sheep-goats | 138.45 | 303.8 | 271.7 | 262.1 | 254.0 | 251.1 |
| Grain yields, 4 year mean (kg ha$^{-1}$) | 323 | 518 | 588 | 682 | 857 | 1057 |
| Manured | 0 | 7260 | 4120 | 3186 | 2402 | 2116 |
| Unmanured | 4845 | 317 | 2581 | 3336 | 3939 | 4198 |
| Total | 4845 | 7578 | 6702 | 6522 | 6341 | 6314 |
| Stover yield, 4 year mean (kg ha$^{-1}$) | 855 | 1310 | 1511 | 1683 | 2171 | 2643 |
| Manured | 0 | 18360 | 10589 | 7863 | 6085 | 5292 |
| Unmanured | 12825 | 841 | 6833 | 8830 | 10428 | 11112 |
| Total | 12825 | 19202 | 17422 | 16693 | 16514 | 16405 |
| Gross Product (CFA) | | | | | | |
| Grains | 484500 | 757812 | 670212 | 652224 | 634190 | 631476 |
| Stover | 128250 | 192022 | 174222 | 166934 | 165140 | 164052 |
| Total | 612750 | 949834 | 844434 | 819159 | 799331 | 795529 |
| total labour cost (CFA) | | | | | | |
| cattle | 138450 | 227556 | 210721 | 206231 | 202274 | 201079 |
| sheep-goats | 138450 | 303848 | 271679 | 262078 | 254032 | 251085 |
| Net benefit (CFA) | | | | | | |
| cattle | 474300 | 722277 | 633712 | 612927 | 597056 | 594449 |
| sheep-goats | 474300 | 645986 | 572754 | 557080 | 545298 | 544443 |
| Marginal rate of return (%) | | | | | | |
| cattle | ref | 235 | 178 | 163 | 152 | 152 |
| sheep-goats | ref | 126 | 96 | 89 | 84 | 84 |

are producing the same quantity of faeces than 12 cattle of 200 kg live weight in average during the course of the year. Livestock deposit a bit more that half of their daily excretions at the night corralling spot (1.6 kg DM d$^{-1}$ per cattle, 0.4 kg kg DM d$^{-1}$ per small ruminant) and the rate of manure application at a spot is determined by the duration of the corralling at the spot, and the geometry of the animal tethering. Based on local practice that geometry was set at 4x4m for cattle and 2x2m for sheep and goats, which result in an estimate of 1t DM $ha^{-1}$ per night of corralling. Again based on local practice, manure is not applied every year as residual effect of manure is expected at least over 4 years. The benefit calculated here only includes millet yield of both grains and stalks (table 78c). These yields are averages over four years, the year following corralling and the three following years in order to account for the residual effect of the manure on millet yields. The labour cost includes the daily handling of the animals at the corralling spot (all animals are tethered) which is heavier for small ruminants because of they are four time as many, the removal of tethering post to a new corralling spot which increases with the frequency of moves, and thus decreases with the rate of manure application. Labour also include weeding time that is set slightly superior in unmanured fields because of the higher infestation by prolific weeds such as Eragrostis tremula and Mitracarpus scaber, while manure application tends to favor more easily removable species such as Jacquemontia tamnifolia and Cenchrus biflorus. Finally, labour includes harvesting time is set proportional to the grain yield.

In a first table (78c), the marginal benefits of the millet crop made by farmers corralling either cattle or small ruminants for durations that determine different rates of manure application, are compared with the benefits made by farmers that are not using cattle manure. Marginal rate of returns of the labour investment made in corralling livestock, including implications on other labour activities, weeding and harvesting, are positive in all cases more so for cattle and for small rate of manure application at a time.

In a second table (78d) same results are used to compare the 'average' farmer practice which consist in moving the corrals every two weeks for cattle (leading to the application of 14t DM $ha^{-1}$) and every week for small ruminants (leading to the application of 6t DM $ha^{-1}$) to more frequent move of corral spots, leading to reduced rate of manure application but on a larger proportion of the land cropped. Indeed with a move of corral spot every 2 nights the farmer applies manure over 3.5 ha every year, and thus can almost cover the whole land once every four years (14ha), while with the present practice he only cover about half an hectare per year thus 2 ha over four years. On the yields, the larger extent of the area manured more than compensate for the reduction in rate of application of manure. This yield increase exceeds largely the increase labour cost implied by more frequent moves of corral locations. The rates of return of the labour investment in moving more frequently corral spots are positive when compared to reference situations where corral are moved every two weeks or every week. The rates of return are higher for cattle and small ruminants.

A first evaluation is done of the simultaneous application of manure by corralled cattle and placed inorganic fertilizer on a millet crop. The residual effect of the treatment over three years is included in considering the average grain and stalks yields over the three years following treatment (Table 78 e). The fertilizer used was NPK 15-15-15 at 6g per hill on a 10000 hill per ha field, applied at sowing the first year.

The calculation of net benefit and return of soil amendment with either manure or mineral fertilizer or both, were done for a 1 ha field and 12 cattle moved corral every week. Only the work of removing the tether posts once a week was charged to the cost of corralling. The daily handling of the animals was not included as the livestock production was not included in the gross product. Gross product included grain and stalks. The increase in yield resulting from the application of NPK only did not pay for the cost of the fertilizer. However, the increase in yield measured over three years following the application of 6t of manure largely paid for the labour cost of corralling and for the impact of corralling on the cropping labour cost leading to a marginal rate of return of the labour investment of 165%. The additional increase in yield observed when corralling is associated with inorganic fertilization also pays for the additional labour and fertilizer costs but with a narrower rate of return on inputs (80%). When the combined application is compared to the sole manure application, the rate of return on the fertilizer and associated investment is only 13%.

**Table 78d** Net benefit and economic return of alternative method to apply manure by corralling either cattle or a mix of sheep and goats on fields cropped in millet at lower rates of application than in the current farmers practice (equivalent to 14t DM/ha for cattle and 6t DM/ha for small ruminants). The details of labour cost and yields are in table 78b.

| **Treatments (rate of manure tDM ha$^{-1}$)** | **14** | **10** | **6** | **4** | **2** |
|---|---|---|---|---|---|
| Area manured in 1 year (ha) | 0.5 | 0.7 | 1.2 | 1.7 | 3.5 |
| Area manured in 4 years (ha) | 2.0 | 2.8 | 4.7 | 7.0 | 14.0 |
| Area unmanured over 15ha (ha) | 13.0 | 12.2 | 10.3 | 8.0 | 1.0 |
| Total labour (adult day) | | | | | |
| Cattle | 201.1 | 202.3 | 206.2 | 210.7 | 227.5 |
| Sheep-goats | 251.1 | 254.0 | 262.1 | 271.7 | 303.8 |
| Total labour cost (CFA) | | | | | |
| Cattle | 201079 | 202274 | 206231 | 210721 | 227556 |
| Sheep-goats | 251085 | 254032 | 262078 | 271679 | 303848 |
| Gross Product (CFA) | | | | | |
| With manure | 631476 | 634190 | 652224 | 670212 | 757812 |
| No manure | 164052 | 165140 | 166934 | 174222 | 192022 |
| Total | 795529 | 799331 | 819159 | 844434 | 949834 |
| Net benefit (CFA) | | | | | |
| Cattle | 594449 | 597056 | 612927 | 633712 | 722277 |
| Sheep-goats | 544443 | 545298 | 557080 | 572754 | 645986 |
| Marginal rate of return /ref 14tDM/ha (%) | | | | | |
| Cattle | ref | 218.3 | 358.7 | 407.2 | 482.8 |
| Sheep-goats | ref | 29.0 | 115.0 | 137.5 | 192.4 |
| Marginal rate of return /ref 6tDM/ha (%) | | | | | |
| Cattle | na | na | ref | 462.9 | 512.8 |
| Sheep-goats | na | na | ref | 163.2 | 212.8 |

The net benefit and return to investments were calculated for the use of alternative mulch material as livestock litter placed at the corralling spots (table 78f). The assessment was done for a one hectare millet crop cultivated over two years following corralling with cattle. Cattle were corralled on the field under contract established in kind (millet bundles per week) between the pastoralist and the farmer (equivalent to 1860 CFA per tone of manure deposited). Two type of organic material were used as mulch at a rate of 2t DM/ha: either millet stalks or coppices of Guiera senegalensis, the dominant shrub in the landscape. Variable cost included the cost of the manure contract, the labour cost involved in the first year harvest, transport and laying of the mulch on the field and also impact on weeding time of mulch and manure depositions. Harvest labour was set proportional to the grain yield. The increase in grain and stalks yields were small compared to control with no mulch nor manure. In consequences the net benefits remain modest. Returns on labour for mulching are slightly higher for Guiera branches than for millet stems. Returns on manure cost are higher at the 3t DM /ha rate of manure application and decreased at higher rate. However, this trend could reverse when a third and a fourth years of residual effects will be included (the experiment is on-going).

**Table 78e**. Net benefit and economic return of soil amendment either with manure applied by corralling cattle on fields cropped in millet at 6t DM/ha (M) or with placed application of 6g NPK 15-15-15 per hill at sowing (F), separately or combined (M+F).

| Treatments | C | M | F | M+F |
|---|---|---|---|---|
| Rate of manure applied (t $ha^{-1}$) | 0 | 6 | 0 | 6 |
| Rate of NPK applied (kg $ha^{-1}$) | 0 | 0 | 60 | 60 |
| Labour (adult day) | | | | |
| corralling | 0 | 9 | 0 | 9 |
| Fertilizer application | 0 | 0 | 2 | 2 |
| Weeding (1+2) | 11 | 9 | 10 | 9 |
| harvest | 3 | 5 | 3 | 6 |
| Total labour (adult day) | 14 | 23 | 15 | 26 |
| Total labour cost (CFA) | 14000 | 23000 | 15000 | 26000 |
| Cost of fertilizer (CFA) | 0 | 0 | 12000 | 12000 |
| Total variable costs (CFA) | 14000 | 23000 | 27000 | 38000 |
| Grain yields, 3 year mean (kg $ha^{-1}$) | 262 | 471 | 310 | 603 |
| Stover yield, 3 year mean (kg $ha^{-1}$) | 853 | 1615 | 924 | 1990 |
| Gross Product (CFA) | | | | |
| Grains | 26200 | 47100 | 31000 | 60300 |
| Stover | 8530 | 16150 | 9240 | 19900 |
| Total | 34730 | 63250 | 40240 | 80200 |
| Net benefit (CFA) | 20730 | 40250 | 13250 | 42200 |
| Marginal rate of return (%) | | | | |
| Reference treatment C | Ref | 217 | D | 89 |
| Reference treatment M | Na | Ref | na | 13 |

Table 78 f : Net benefit and economic return of cattle manure application at either 6, 12 or 18 t $ha^{-1}$ through animal corralling, associated or not with bedding with either millet stalks or Guiera branches at 2 t $ha^{-1}$.

| **Treatments** | ***Control*** | | | ***3tM*** | | | ***6tM*** | | | ***12tM*** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rate of manure applied (t $ha^{-1}$) | *0* | *0* | *0* | *3* | *3* | *3* | *6* | *6* | *6* | *12* | *12* | *12* |
| Type of mulch applied (2t $ha^{-1}$) | *0* | *M* | *B* | *0* | *M* | *B* | *0* | *M* | *B* | *0* | *M* | *B* |
| **Labour (adult day)** | | | | | | | | | | | | |
| Clearing & mulching | *1,0* | *2,0* | *3,0* | *1,0* | *2,0* | *3,0* | *1,0* | *2,0* | *3,0* | *1,0* | *2,0* | *3,0* |
| Weeding (1+2) | *6,0* | *7,0* | *8,0* | *4,0* | *5,0* | *6,0* | *4,0* | *5,0* | *6,0* | *4,0* | *5,0* | *6,0* |
| harvest | *1.6* | *2.0* | *2.4* | *3.0* | *2.7* | *4.2* | *3.0* | *3.4* | *4.0* | *4.5* | *4.4* | *4.6* |
| Total labour (adult day) | *8.6* | *11.0* | *13.4* | *8.0* | *10.7* | *13.2* | *8.0* | *10.4* | *13.0* | *9.5* | *11.4* | *13.6* |
| **Total labour cost (CFA)** | 8600 | 11000 | 13400 | 8000 | 10700 | 13200 | 8000 | 10400 | 13000 | 9500 | 11400 | 13600 |
| Cost of manuring (CFA) | 0 | 0 | 0 | 5580 | 5580 | 5580 | 11160 | 11160 | 11160 | 22320 | 22320 | 22320 |
| **Total variable costs (CFA)** | 8600 | 11000 | 13400 | 13580 | 16280 | 18780 | 19160 | 21560 | 24160 | 31820 | 33720 | 35920 |
| Grain yields, 3 year mean (kg $ha^{-1}$) | 161 | 199 | 245 | 300 | 268 | 419 | 303 | 342 | 405 | 447 | 437 | 459 |
| Stover yield, 3 year mean (kg $ha^{-1}$) | 497 | 692 | 918 | 1223 | 1162 | 1554 | 1145 | 1452 | 1815 | 1907 | 1942 | 2035 |
| **Gross Product (CFA)** | | | | | | | | | | | | |
| Grains | 16100 | 19900 | 24500 | 30000 | 26800 | 41900 | 30300 | 34200 | 40500 | 44700 | 43700 | 45900 |
| Stover | 4970 | 6920 | 9180 | 12230 | 11620 | 15540 | 11450 | 14520 | 18150 | 19070 | 19420 | 20350 |
| **Total gross product** | 21070 | 26820 | 33680 | 42230 | 38420 | 57440 | 41750 | 48720 | 58650 | 63770 | 63120 | 66250 |
| **Net benefit (CFA)** | 12470 | 15820 | 20280 | 28650 | 22140 | 38660 | 22590 | 27160 | 34490 | 31950 | 29400 | 30330 |
| **Marginal rate of return (%)** | | | | | | | | | | | | |
| **Reference treatment Control** | ref | 139,6 | 162,7 | 324,9 | 125,9 | 257,3 | 95,8 | 113,3 | 141,5 | 83,9 | 67,4 | 65,4 |

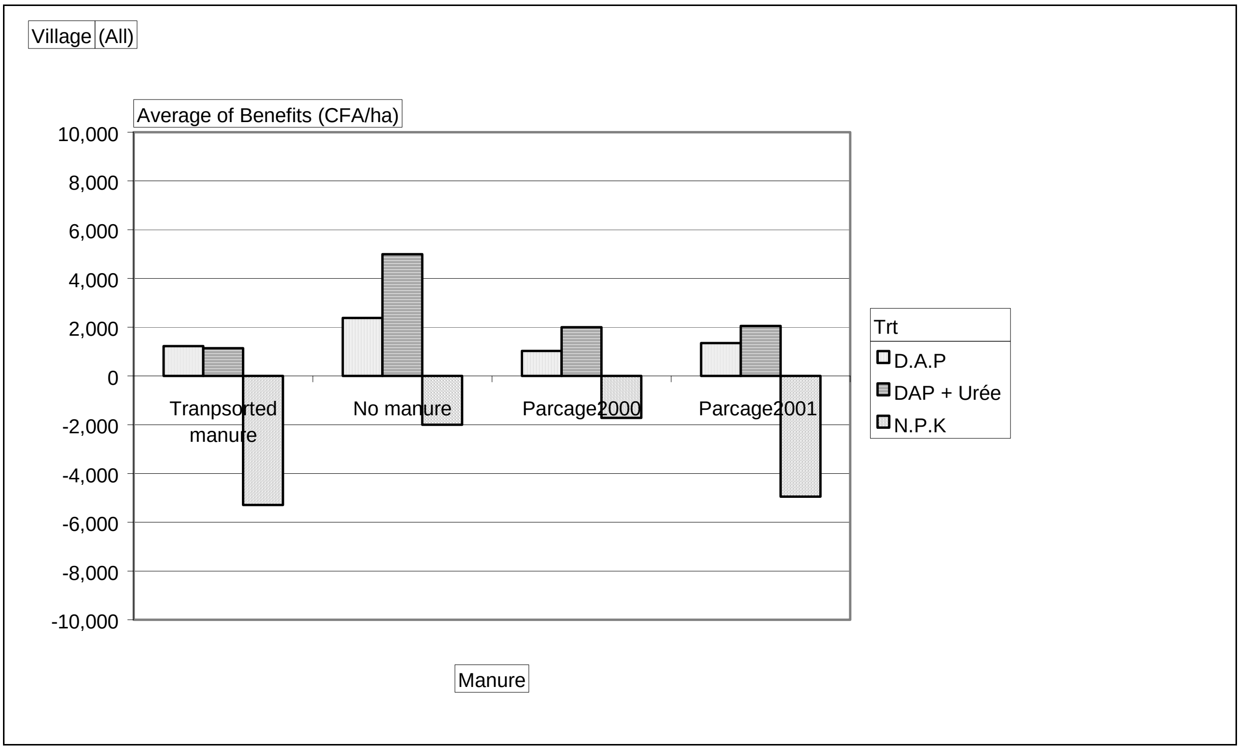
Application of placed inorganic fertilizer on millet

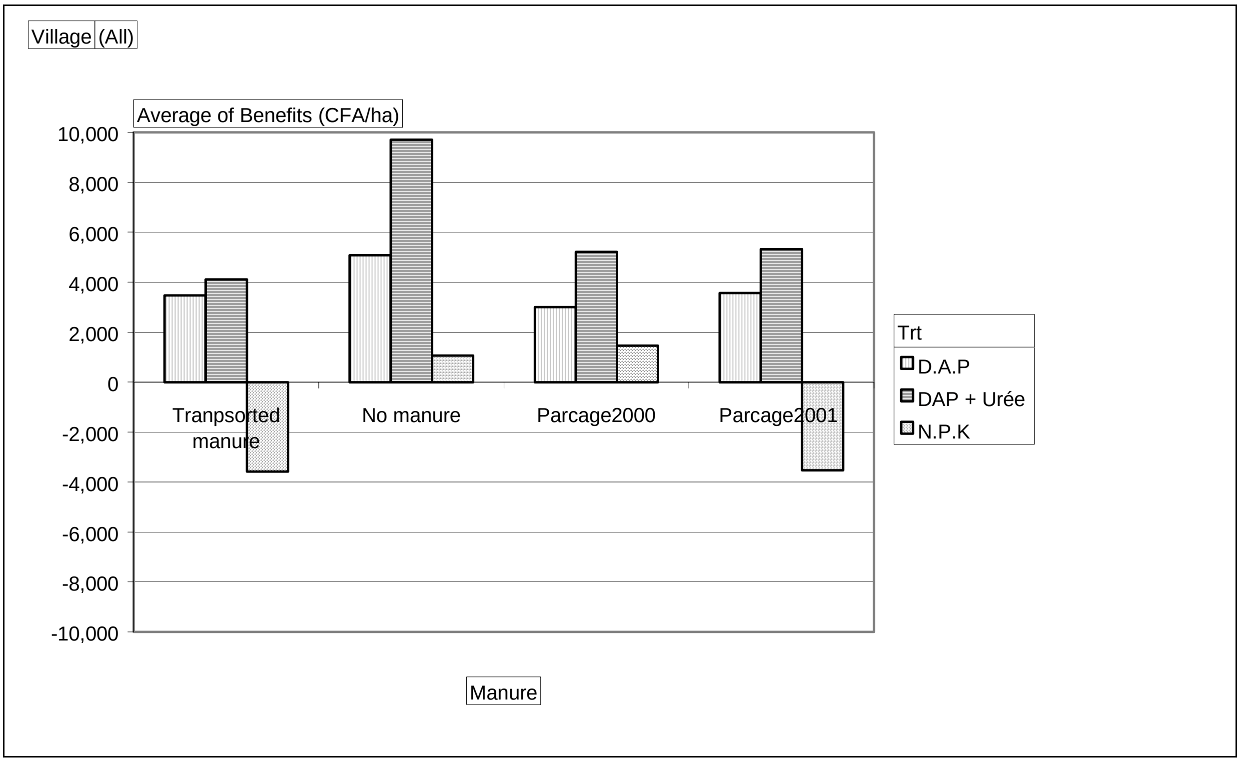
Data from the P response curves experiment of a nearby plot which had been under fallow for the past five years, confirmed the optimum rate of 8 kg $P_2O_5$ $ha^{-1}$ for millet. Benefit to cost ratio established for grain alone revealed ratios ranging from 18 for 2 kg $P_2O_5$ $ha^{-1}$ to 9 for 12 kg $P_2O_5$ $ha^{-1}$. The Benefit to cost analysis assumes cfa 12,000 as the cost of 50 bag of DAP fertilizer and cfa 10,000 as the average market price of 100 kg bag millet grain. Certainly, the ratios will be greater than what was recorded above, if the value of the additional stover could be appraised in monetary terms.

The economical analysis of the fertilizer demonstration trials in 2001 rainy season (figure 8) show on average a negative or very small return of NPK 15-15-15 fertilizer in all cases (all manure classes and millet price of 100 and 150 CFA/kg) due to the fact that the cost per fertilizer unit of 15-15-15 is 2.6 time the one of DAP (NPK 50 kg bag at 10,000 CFA against 11,500 for DAP). Having the some agronomical performance between DAP and NPK 15-15-15, the initial recommendation of using NPK 15-15-15 should be dropped and in replacement TSP fertilizer should be tested during the next rainy season. The best average return was obtained by using DAP+Urea on non manured fields. Other demonstrations monitored by FAO in other regions of Niger had a much better economical return.

The empirical statistical model for the estimation of pearl millet grain yield as function of fertilizer treatment, manure amendment, management practices could be use in a decision support system. Further research is required to improve the model by including soil water balance and drought index parameters. The empirical model should be validated on in independent site and compared with adapted crop growth models.

**Figure 8**. Average benefits in 2001 on the use of mineral fertilizer for A) millet price of 100 CFA/kg at harvest and B) a millet price of 150 CFA/kg as expected using the inventory credit scheme implemented by FAO.






3.6. Pathways for diffusion and adoption

Locally, farmers and extension agents were involved in the design and evaluation of experimental trials and results were discussed with them. Special effort was made to help farmers' associations gain access to credit to pay for inputs, especially inorganic fertilizers in the district of Dantiandou, and also in IFAD funded project areas in Maradi-Aguié and Tillabéry. The principle of the project was to first get the communities organised into farmer (or women) associations which could have access to credit at the local Credit and Saving Mutual (based in Dantiandou). The access to inputs was facilitated through warrantage which implied the building of a collective storing facility in each village. Initiated in 1999 on an informal and information-sharing basis a collaboration with the project of FAO and the Agricultural Division or the Ministry of Agriculture and Livestock of Niger (GCP/NER/038/BEL) strengthen and expand in 2000 and 2001 to include ICRISAT and NGO's partners (Micro-realisation GTZ, Acquadev).
The objectives of the collaboration were to test and demonstrate to and with farmers the benefits of technologies that had been validated on-station and on-farm by research institutions including INRAN, ILRI and ICRISAT. Among the technologies tested:

- Placed application of micro-doses of inorganic fertilizer on millet (6g NPK 15-15-15 or 2g DAP per hill, also 1g of urea in 2001, corresponding to rate of 4 kg P $ha^{-1}$ or 9 kg $P_2O_5$ $ha^{-1}$). This was applied to millet cropped on land with different histories of livestock manure application.
- Test of dual purpose cowpea breeds intercropped with millet.
- Test of donkey tracted implements to weed millet fields
- Test cheap diets to fatten sheep based on cowpea haulms, millet bran and locally available roughages

The demonstration trial on millet fertilization was implemented by 120 farmers in 10 villages of the Dantiandou district (were ILRI had been working since 1994) in 2000 and 140 in

2001and by 140 farmers in 2001.  Moreover, the same trial was implemented by 440 other farmers in different regions of the country, leading to a total of 580 demonstrations. Cowpea and sheep fattening trial were conducted by 24 farmers in 2001. A demonstration weed implement was distributed in each village, and training provided for its use. These demonstration trials were also very valuable to enhance the dialogue between the rural world development body and research and to allow collaborative fine-tuning of technologies.

At the regional level, information on project activities and results was made available to state extension services and development projects, especially IFAD funded projects in Tillabery and Maradi -Aguié, FAO 'Input programme' in central and western Niger and Aquadev project in eastern Niger. In addition, demonstration trials, open days and reciprocal farmers' visits were organised as part of an information dissemination strategy.

## 4. Sites in the irrigated lands of Niger.
### 4.1. Farming systems and benchmark site of irrigated system in Niger

Due to a number of peculiar features: rich alluvial soils, availability of water for irrigation and proximity of the town of Niamey, the irrigated systems along the river Niger valley in Kollo were treated as a special benchmark site. Among the village surveyed in the initial rapid participatory appraisal two of the villages had part of their lands in the Niger valley: Youri Say and Niamé.

In spite of higher agronomic potential of alluvial soils farming systems in the irrigated benchmark site remain largely subsistence-oriented. The endowment resources of the farmers do not differ markedly from the farm endowment observed elsewhere in Western Niger (table 79). The main crop is rice with some sorghum and millet in the uplands. The close proximity of the urban market encourages the production of vegetables (e.g. okra, lettuce, tomatoes, carrots etc.), tuber crops (e.g. cassava and sweet potatoes), fruit trees (e.g. *Moringa oleifera*, mango and citrus) and dairy production. Cattle and sheep fattening is also common due to easy access to feed supplements (bran from grain mills and brewers' waste from the breweries) and the urban market.

**Table 79** Average resource endowments by class category and information on IFAD and FAO funded projects in study villages in Niger

| Benchmark site | Villages | Category | Land Area (ha) | Cattle (head) | Sheep (head) | Goats (head) | Nature of IFAD Project |
|---|---|---|---|---|---|---|---|
| Tillabéry | Youri Say | High | 25.7 | 19 | 5 | 12 | |
| | | Medium | 4.4 | 10 | 0 | 13 | |
| | | Low | 6.3 | 9 | 3 | 5 | |
| | Niamé | High | 22 | 0 | 0 | 0 | * 1993- Prospecting<br>* 1997- Pepper production |
| | | Medium | 12.3 | 3 | 5 | 4 | |
| | | Low | 11.3 | 1 | 3 | 3 | |

The proximity of the town of Niamey and smaller cities of Tillabéry, Kollo and Say, favor the development of market -oriented farms at the periphery of the towns, managed or at least funded by urban citizen such as traders, civil servants, retired persons willing to invest in farming activities. Some of the technological tests were conducted in such farms at Kirkissoye (a cooperative of producers), Karey Gorou, Sidi Koara, N'dounga and Kollo. A special survey was carried out on peri-urban Niamey dairy farms. The survey dealt with production and reproduction parameters of the dairy herds, as well as economic variables with a cost benefit assessment. Out of estimated 220 dairy farms in peri-urban Niamey, 74 farmers were surveyed with 23 organized in cooperatives and 51 are private farmers. Management differ between the two type of farms, with more inputs by the cooperative than the private, this also reflects in the composition of the herd (table 79b) and the production parameters (table 79c). A monitoring was done for milk yields which classically fluctuate with seasons, with higher fluctuations for the herds of the private farmers that are grazing and given less supplements than cooperative one's. (Figure 8b and 8c)

**Table 79b**. Composition of dairy cattle herds in peri-urban Niamey for cooperative and private farmers.

| Farm type | Nb of farms | Herd composition (%) | | | | |
|---|---|---|---|---|---|---|
| | | Calf | Steer | Bull | Heifer | Cow |
| Cooperative | 23 | 26 | 11 | 3 | 23 | 27 |
| Private | 51 | 39 | 8 | 2 | 10 | 39 |

**Figure 8b** Seasonal fluctuations of daily milk yield per cow in private dairy farm in peri-urban Niamey.

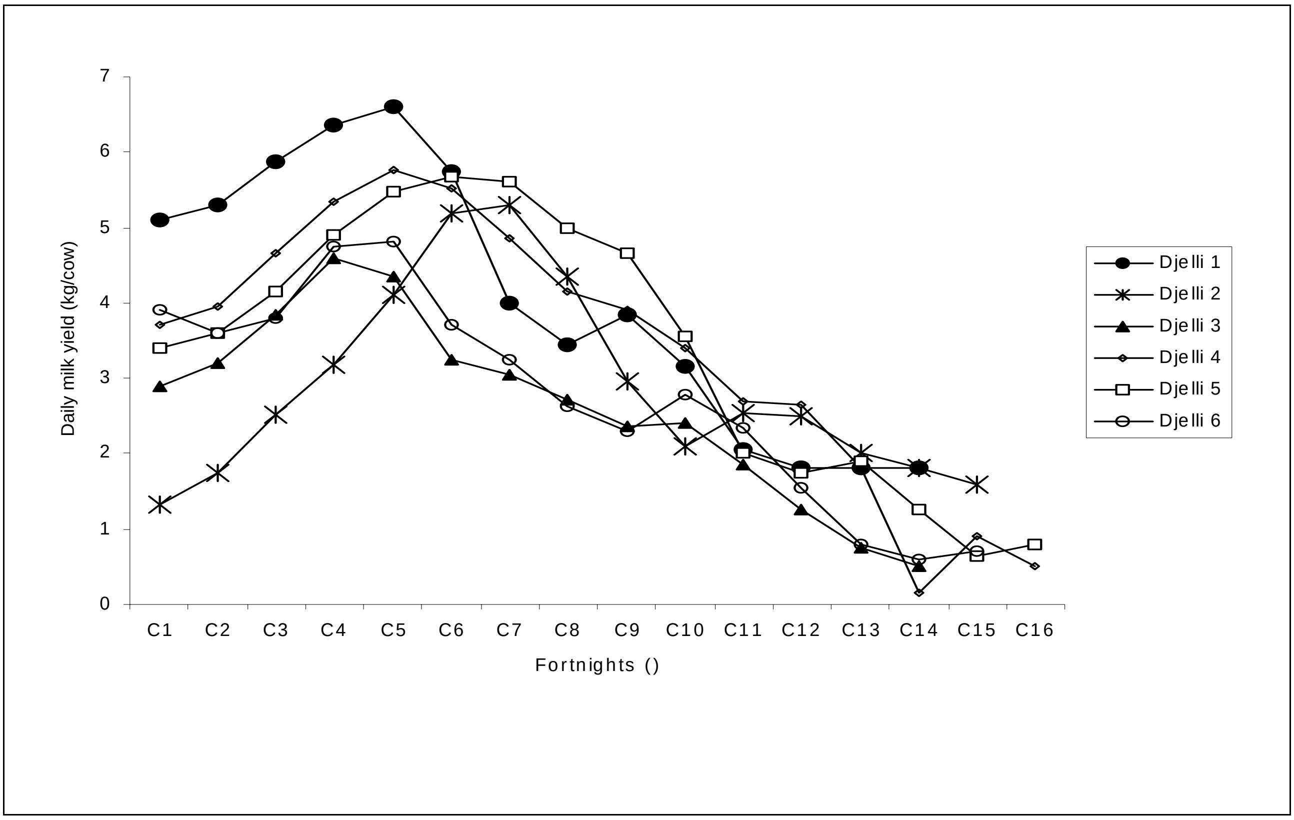


Table 8c. Seasonal fluctuations of daily milk yield per cow in cooperative dairy farm in peri-urban Niamey.

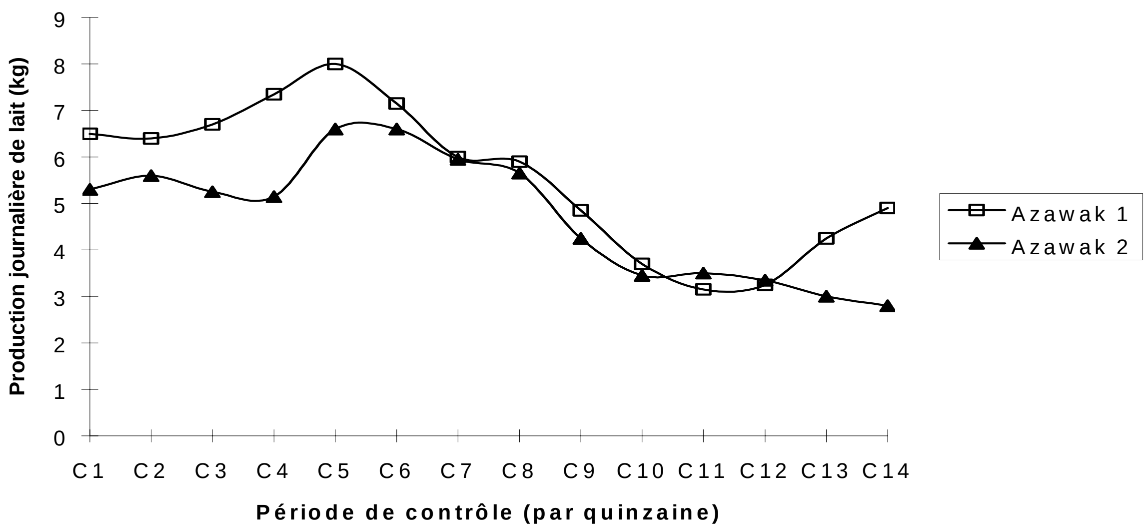



**Table 79c.** Milk and reproduction parameters of peri-urban Niamey dairy farms for the cooperative and the private farmers.

| Farm types | Nb. of farms | Age at 1st calving | Duration of lactation | Interval between calving | Age at culling | Mortality % | | Milk yield kg/d/cow | | | Herd milk yield |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | m | m | m | y | Young | adults | Dry cool | Dry hot | Wet | kg/y |
| Cooperative | 23 | 38.3 | 13.8 | 9.0 | 13.6 | 7.1 | 4.3 | 3.2 | 4.1 | 2.7 | 4956 |
| Private | 51 | 41.5 | 12.6 | 8.7 | 16.4 | 12.5 | 5.7 | 4.1 | 2.8 | 3.3 | 7644 |

The economic data were used to assess the profitability of the dairy enterprise for each farm type. It appears that the increased productivity of the cooperative farmers was not sufficient to cover their highest cost of production. Actually only the private farmers were beneficiary (table 79d). A large fraction (77%) of the additional cost in the cooperative farms is due to feed, it is thus determinant to find cheapest diets that could increase and stabilize across season individual cow milk yields.

**Table 79d.** Economic assessment of dairy production of dairy farms in peri-urban Niamey for cooperative and private farmers.

| Product, cost and benefits Per farm and per year (CFA) | Farm types | |
|---|---|---|
| | Cooperative | Private |
| Milk product | 128338 | 350364 |
| Meat product | 52141 | 94256 |
| Manure product | 14864 | 9254 |
| **Total product** | **195343** | **453874** |
| Feed cost | 237055 | 157503 |
| Labor cost | 13335 | 2940 |
| Veterinary cost | 5125 | 775 |
| Dues | 6868 | 0 |
| Infrastructure | 3732 | 3672 |
| Equipement | 2293 | 164 |
| **Total cost** | **268408** | **165054** |
| Capital invested | 483411 | 402053 |
| Benefit net | -73065 | 288820 |
| Return (%) | -15 | 72 |

### 4.2. Technological options for more efficient crop-livestock integration

Initial surveys conducted 1998 in three agro-ecological zones of Niger included two villages from the Niger valley. In spite of the higher inherent fertility of alluvial soils which extend on part of the village land, the decline of soil fertility, including in the irrigated rice fields, was pointed as one major constraint for productivity. The cost of inorganic fertilizer inputs recommended by local extension services (200kg Urea + 300 kg 15-15-15 $ha^{-1}$) was considered unaffordable. This lead to propose and test on-farm the use of composts associated or not to local rock phosphate as an alternative to inorganic inputs on either irrigated rice or the 'burgu' (Echinochloa stagnina) forage crop. The compost was made from livestock excretions (mostly cattle), feed refusals including rice straws and house wastes. However, the lack of fodder resources for livestock during the late dry season was also mentioned as a limiting factor of productivity and crop-livestock integration. A specific survey was carried out to assess sheep, goat and cattle foraging grazing behavior at Sidi Koira (table 80) to document farmer's perception of multiple use and values of browse species.

**Table 80**: Time spent (hour. Minutes) in different activities during grazing day by cattle, sheep and goats at Sidi Koira, Say - Niger

| Livestock activities | November 98 | | | May 99 | | | August 99 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cattle | Sheep | Goat | Cattle | Sheep | Goat | Cattle | Sheep | Goat |
| Walking | 0:59 | 0:00 | 1:34 | 0:43 | 1:03 | 1:06 | 1:36 | 1:49 | 1:52 |
| Grazing | 5:43 | 5:26 | 5:50 | 6:00 | 6:07 | 5:45 | 6:51 | 5:47 | 5:26 |
| Drinking | 0:12 | 0:06 | 0:07 | 1:49 | 1:12 | 1:50 | 0:19 | 1:08 | 1:01 |
| Ruminating | 1:16 | 1:09 | 0:32 | 1:00 | 1:51 | 1:01 | 0:18 | 0:32 | 0:46 |
| Resting | 0:07 | 0:27 | 0:15 | 0:22 | 0:30 | 0:25 | 0:09 | 0:06 | 0:15 |
| Total day | 8:19 | 8:09 | 8:21 | 9:50 | 10:24 | 10:07 | 9:12 | 9:22 | 9:20 |

Livestock behavior, management and performance documented in Sidi Koira were compared to similar data collected at Bengou, under more humid climate and in a more intensively cropped environment, and also at Toukounous a more arid, yet intensively cropped site of western Niger. At Sidi Koira, significant differences were found between cattle, sheep and goats in the time spent walking (more with goats), grazing, ruminating(less with goats) and resting (more with sheep) during late dry season.

Species feed preferences between herbaceous, millet crop residues and different browse species were also established at the different seasons (table 81) as well as speeds and distances covered along daily grazing orbits by each animal species (table 81b).

**Table 81**. Grazing selection of cattle, sheep and goat at harvest, mid dry and mid wet seasons (hour:minutes) spend grazing different types of fodder; Sidi Koira, Say, Niger.

| Type of fodder grazed | November 98 | | | May 99 | | | August 99 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cattle | Sheep | Goat | Cattle | Sheep | Goat | Cattle | Sheep | Goat |
| Herbaceous | 3:29 | 4:58 | 3:32 | 0:45 | 2:30 | 0:19 | 6:51 | 5:47 | 4:11 |
| Millet stalks | 1:57 | 0:05 | 0:03 | 2:33 | 2:01 | 0:41 | - | - | - |
| Browses | 0:17 | 0:12 | 2:05 | 2:42 | 1:16 | 4:45 | 0:00 | 0:00 | 1:15 |
| Total grazing | 5:43 | 5:25 | 5:50 | 6:00 | 6:07 | 5:45 | 6:51 | 5:47 | 5:26 |

**Table 81b**. Speed and daily distances walked by grazing cattle, sheep and goats in Sidi Koira (Western Niger). Average of observations at three seasons (November 98, May and August 1999)

| Activity | Cattle | | Sheep | | Goats | |
|---|---|---|---|---|---|---|
| | Speed | Distance | Speed | Distance | Speed | Distance |
| Walking | 2.996 | 2.942 | 2.420 | 2.428 | 1.796 | 2.834 |
| Grazing | 0.710 | 4.069 | 0.682 | 3.710 | 0.490 | 2.970 |
| Overall | 0.842 | 7.015 | 0.715 | 6.130 | 0.682 | 5.254 |

The observations highlight the major contribution of browse to goats diet, even during the wet season, and the strategic role of browses by the end of the dry season for cattle and sheep. It also indicate a strong species selectivity of browsing with species such as Balanites aegyptiaca totaling 48% of goats browsing time while it only constitute 0.42% of the woody population, and Guiera senegalensis with 14% of browsing time for a share of 98.8% of the woody plan population. Yet intensification of land use reduces the density of palatable woody plants to the benefit of poorly or not palatable such as Guiera senegalensis (98% of woody plant population at Sidi Koira) Prosopis juliflora, Manguifera indica or Eucaliptus ssp and 14% of the cattle are already in poor body condition at the onset of the dry season. A trial was thus done to establish in N'dounga a fodder bank with preferred browse species adapted to the climate and to alluvial soils: Bauhinia rufescens, Kigelia africana, Ziziphus mauritiana; Prosopis africana and Leucaena leucocephala. First trials to feed cuttings to sheep were carried out in 2001.

The proximity of the urban market give incentive to dairy production. A survey was conducted in 2001 to assess the importance of dairy production in the surroundings of Niamey: 74 of the estimated 220 producers were interviewed and their herd monitored. Two different type of management were identified: one relatively extensive where cows large feed themselves through grazing, and a more intensive where cows are fed at the barn. Feed represent 88 and 95% of variable cost respectively, and is such that dairy production is not beneficial at the present price of milk in the more intensive system. This lead to research of more efficient and cheapest diet based on rice straws enriched with urea, wheat bran and brewers' wastes both available from Niamey's mill and brewery.

The proximity of market also renders attractive cattle and sheep fattening. However, feed availability, quality and price render fattening risky. Thus, a parallel trial was carried out to test the efficacy and economic value of diets based on rice straws enriched with urea associated with wheat bran and brewers' waste.

### 4.3. Ex-ante economic impact assessment

<u>Irrigated rice crop on soil amended with compost enriched with rock phosphate.</u>
An ex-ante analysis was done of the five alternative compost amendments substituted to inorganic fertilizer application on irrigated rice in a Niger valley farm (table 82). The amendments using 6t of plain compost, or compost enriched with 8% of rock phosphate were not more profitable than the farmer practice based on the use of 200 kg of Urea and 300 kg of NPK per hectare, while the use of compost enriched with 4, 12 and 16% were more profitable.

**Table 82**: Ex-ante assessment of alternative soil amendments on irrigated rice production.

| Parameters per hectare of irrigated rice | Urea + NPK | 6t Compost | 6t Compost + 4% RP | 6t Compost + 8% RP | 6t Compost + 12% RP | 6t Compost + 16% RP |
|---|---|---|---|---|---|---|
| Grain yield (kg) | 6767 | 6673 | 7096 | 672 | 7284 | 6532 |
| Straw yield (kg) | 6814 | 5052 | 7557 | 5052 | 5639 | 5522 |
| Gross product(CFA) | 718054 | 681402 | 759552 | 685632 | 745784 | 676232 |
| Labor cost (CFA) | 197500 | 203500 | 203500 | 203500 | 203500 | 203500 |
| Input cost (CFA) | 161000 | 153625 | 157750 | 165750 | 173750 | 181750 |
| Total variable cost (CFA) | 358500 | 357125 | 361250 | 369250 | 377250 | 385250 |
| Net benefit (CFA) | 359554 | 324277 | 398302 | 316382 | 368534 | 390982 |
| Marginal rate of return(%) | - | D | 816 | D | 43 | 108 |

**Diary cow supplementation with wheat bran, brewer's wastes and urea**
An ex-ante economic analysis was done of alternative dairy cow supplementation (table 83). Results indicate that alternative diets dominate current farmer practices and are likely to be more profitable.

**Table 83**. Marginal analysis of proposed dairy cow supplementation trials in peri-urban area of Niamey, Niger.

| Technical and economic parameters | Treatments | | |
|---|---|---|---|
| | Control: Rice straw ad libitum + wheat bran + salt | Rice straw 7 kg $d^{-1}$ + wheat bran 1.5 kg $d^{-1}$ + brewer's waste 1kg $d^{-1}$ | Rice straw 7 kg $d^{-1}$ + wheat bran 2 kg $d^{-1}$ + brewer's waste 1 kg $d^{-1}$ |
| Milk yield litres $cow^{-1}$ $d^{-1}$ | 1 | 2.5 | 3.0 |
| Manure yield kg $d^{-1}$ | 4 | 4 | 4 |
| Gross product (CFA) | 245 | 545 | 645 |
| Labor cost (CFA) | 25 | 25 | 25 |
| Input cost (CFA) | 195 | 216 | 245 |
| Total cost (CFA) | 220 | 241 | 270 |
| Net benefit (CFA) | 25 | 304 | 375 |
| Marginal rate of return (%) | - | 1330 | 700 |

**Cattle fattening with a diet including wheat bran, brewer's wastes and urea**
An ex-ante economic analysis was done of an alternative diet to fatten steers, oxen and culled bulls (table 84). Results indicate that the alternative diet dominates current farmer practices and is likely to be more profitable.

**Table 84**. Marginal analysis of a proposed steers fattening trials in peri-urban area of Niamey, Niger.

| Technical and economic parameters | Treatments | |
|---|---|---|
| | Control: Farmer practice: 3-4 kg $d^{-1}$ rice straws + wheat bran 1.5 kg $d^{-1}$+ salt | Rice straw 4 kg $d^{-1}$ + wheat bran 2.5 kg $d^{-1}$ + urea lick |
| Weight gain g $d^{-1}$ | 300 | 600 |
| Manure produced kg $d^{-1}$ | 12 | 12 |
| Gross product (CFA) | 17350 | 32200 |
| Labor cost (CFA) | 2250 | 2250 |
| Input cost (CFA) | 11960 | 11460 |
| Total cost (CFA) | 15210 | 19710 |
| Net benefit (CFA) | 2140 | 12490 |
| Marginal rate of return (%) | - | 230 |

### 4.4. Project implementation, trials and results

<u>Use of compost enriched with rock phosphate on irrigated rice and 'burgu'</u>

Initiated in 1999 a trial compost trial was conducted with 6 farmers at Kirkissoye, in the valley of the Niger River. The compost was made of 25% rice straw, and 75% cattle manure using 2liters of water per kg of compost. The compost was enriched with 0, 4, 8, 12 or 16% dry weight of rock phosphate. The trial consisted in comparing the application of 6t $ha^{-1}$ of each of these composts to the farmers practice of using inorganic fertilizers at 200 kg $ha^{-1}$ urea plus 300 kg $ha^{-1}$ of NPK 15-15-15 on an irrigated rice field (Rice breed IR 15). The trial follow a factorial design with four replications  The  effect of soil amendment was observed on the density of tillers, the heights of the plants, the grain and straw yields of the rice.

In 1999, rice yields measured in irrigated farmers fields were very high (6845 kg $ha^{-1}$ of paddy in average) but were not significantly different from each other except for the average weight of 1000 grains which was inferior in the control and superior in the highest input treatment (table 85).

**Table 85**: grain yield, higth of plant, number of tillers and weight of 1000 grains as a function of soil amendments (Karey Gorou 1999).

| Soil amendments | Grain yield (kg/ha) | Higth (cm) | Tiller/plant | Weight of 1000 grains (g) |
|---|---|---|---|---|
| Urea + NPK | 6767 | 98.20 | 17.8 | 25.06a |
| 6t compost | 6673 | 102.6 | 19.2 | 27.14b |
| 6t compost + 4% RP | 7096 | 107.8 | 19.8 | 27.84b |
| 6t compost + 8% RP | 6719.8 | 108 | 20.2 | 27.25b |
| 6t compost + 12% RP | 7284 | 104.6 | 18 | 27.74b |
| 6t compost + 1-% RP | 6532 | 104.4 | 19 | 29.85c |
| Mean | 6845.3 | 104.27 | 19 | 27.48 |
| Significance | $\alpha$=0.82 | $\alpha$=0.63 | $\alpha$=0.44 | $\alpha$=0.002 |

In 2001, the application of compost enriched or not with rock phosphate (PNT) had a significant effect on the number of tillers per plant of rice (P=0,009), however the density of tillers was higher when the compost was not enriched with rock phosphate (Duncan test at P = 0.05). Compost application also enhanced plant growth in height (P=0.0001), with a small but not significant additional effect of rock phosphate (table 86). These differences in growth translated into differences in grain yield, largely superior with compost than with inorganic fertilizer (P=0.0001). Among the plots amended with compost grain yield was also superior for the highest rate of enrichment with rock phosphate (16%), reaching almost twice the yield obtained with inorganic fertilizers. On the other hand, straw yields did not differ with treatments.

**Table 86**. Effects of different options of soil amendments on irrigated rice growth and yields in 2001 at Kirkissoye (Niger valley). Amendments include 200 kg ha$^{-1}$ urea plus 300 kg ha$^{-1}$ of NPK 15-15-15 ; or 6t of compost enriched with 0, 4, 8, 12 or 16% dry weight of rock phosphate .

| Soil amendments | Tillers/plant | | | Plant height (cm) | | | Grain yield (t ha$^{-1}$) | | Straw yield (kg ha$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | | Std | Mean | | Std | Mean | Std | Mean | Std |
| Urea + NPK | 22,00 | a | 3, 8 | 68, 35 | a | 4, 51 | 3,80 a | 0,47 | 7, 35 a | 1, 2 |
| 6t compost | 32,97 | c | 5, 6 | 78, 30 | b | 1, 53 | 5,45 b | 0,56 | 8, 67 a | 1, 3 |
| 6t compost + 4% RP | 25,15 | ab | 2, 7 | 80, 47 | b | 2, 65 | 6,75 b | 0,43 | 6, 55 a | 0, 6 |
| 6t compost + 8% RP | 27,47 | b | 4, 8 | 78, 62 | b | 1, 32 | 6,75 b | 0,83 | 6, 64 a | 3, 3 |
| 6t compost + 12% RP | 31,10 | b | 2, 4 | 81, 05 | b | 1, 15 | 6,75 b | 0,83 | 7, 61 a | 2, 0 |
| 6t compost + 16% RP | 27,60 | b | 1, 7 | 81,09 | b | 2, 93 | 7,10 c | 0,73 | 7, 45 a | 1, 8 |

**Diary cow supplementation with wheat bran, brewer's wastes and urea**
In 2001 a nutrition trial was run on dairy cattle with 20 farmers. The diets tested included rice straws *ad libitum*, urea licks and one of three levels of a half-half mix of wheat bran and brewery draff : 1.5 , 2.5 and 3.5 kg d$^{-1}$. Each farmer has tried one diet on a minimum of 3 Azawak cows which rank of parity varied between 1 and 5. Intake, milk extracted, weight changes of the cow and the calf were monitored and input costs recorded. In the feed trial for dairy cows in peri-urban Niamey, milk yield increased with the proportion of concentrate (wheat bran + brewery draff) fed to the cows whatever was the rank of parity of the cow

(table 87). This increase in milk yield was not obtained at the detriment of the growth to the calf which was superior with 2.5 and 3.5 kg of concentrate for both male and female calves (table 87 b).

**Table 87**: Milk extracted from Azawak zebu cows fed rice straws, urea licks and diverse amount of concentrate made of wheat bran and brewers' wastes

| Concentrate | Rank of parity of the cow | | | | |
|---|---|---|---|---|---|
| kg $d^{-1}$ | 1 | 2 | 3 | 4 | 5 |
| 1.5 kg | 2.28 ±0.93 | 2.53 ±0.76 | 2.52 ±1.18 | 2.68 ±0.18 | 2.69 ±0.88 |
| 2.5 kg | 2.97 ±1.22 | 3.27 ±1.2 | 4.13 ± 0.74 | 3.64 ± 0.93 | 4.13 ±1.38 |
| 3.5 kg | 4.10 ±0.95 | 4.59± 0.56 | 5.26 ± 0.82 | - | - |

**Table 87b**: Weight at birth and daily growth of male and female calves during the six first months from Azawak zebu cows fed rice straws, urea licks and diverse amount of concentrate made of wheat bran and brewers' wastes

| Concentrate | Weight at birth (kg) | | Daily growth rate (g $d^{-1}$) | |
|---|---|---|---|---|
| kg $d^{-1}$ | female | Male | female | male |
| 1.5 kg | 18.5 ± 1.1 | 20.4 ± 2.6 | 162.9 ± 41.6 | 138.0 ± 047.1 |
| 2.5 kg | 20.9 ± 0.6 | 20.8 ± 1.2 | 236.0 ± 87.5 | 246.1 ± 126.5 |
| 3.5 kg | 20.2 ± 0.6 | 20.6 ± 1.6 | 219.0 ± 96.2 | 234.9 ± 162.2 |

However, the body condition of lost half a degree during the monitoring  whatever the diet, the manure produced was not affected either by the proportion of concentrate feed  fed to the cows (table 88).

**Table 88**: Mean weight gains of dairy cows fed with different quantities of concentrate made of half-half wheat bran and brewery draff by farmers of peri-urban Niamey (Kirkissoye), 2001.

| Concentrate | weight gain | Body condition | | manure |
|---|---|---|---|---|
| kg $d^{-1}$ | kg $d^{-1}$ | Initial | Final | kg $d^{-1}$ |
| 1.5 | ± | 3 | 2.5 | 4.32 ± 1.76 |
| 2.5 | ± | 3.5 | 3 | 4.54 ±1.55 |
| 3.5 | ± | 3.5 | 3 | 4.84 ± 1.26 |
| All | ± | 3.3 | 2.8 | ± |

**Cattle fattening with a diet including wheat bran, brewer's wastes and urea**

In 2001, a steer fattening trial has been conducted with 20 farmers from villages of the Niger river valley close to Kollo, in the peri-urban zone of Niamey. The fattening diets included rice straws ad libitum, Urea licks and one of three levels of wheat bran: 1.5 , 2.5 and 3.5 kg $d^{-1}$. Each producer tested on of the diet on young steers 100-125 kg of weight at the onset of a 90 days fattening.  Steers weight changes were monitored, as well as feed intake, labor and input costs. Steer weight gain increased with the quantity of wheat bran included in the diet the rate of wheat bran included in the diet (table 89). Indeed, in three month the mean weight gain of the steers 32, 39 and 47 for 1.5, 2.5 and 3.5 kg $d^{-1}$ of wheat bran respectively. Body condition of the steers also increased more as more bran was included in the diet as well as manure production per animal although differences there were not statistically significant.

**Table 89**: Mean weight gains of steers fattened in the peri-urban Niamey (Kirkissoye), 2001.

| Diet: wheat bran | weight gain | Body condition | | manure |
|---|---|---|---|---|
| kg $d^{-1}$ | kg $d^{-1}$ | Initial | Final | kg $d^{-1}$ |
| 1.5 | 352.5 ± | 2 | 3.5 | 2.32± 0.52 |
| 2.5 | 436.1 ± | 2 | 4 | 2.41 ±0.52 |
| 3.5 | 519.7 ± | 2 | 4.5 | 2.84 ±0.25 |
| All | 433.8 ± | 2 | 4 | |

<u>Establishment of a browse fodder bank and browse supplementation of sheep</u>
A browse forage bank trial was initiated since 1999 in N'douga, in the Niger River valley with three woody plant species that were selected with farmers. *Bauhinia rufescens, Kigelia africana Ziziphus mauritiana and Prosopis africana*. In 2001 the growth of the plants was monitored and sheep were feed cutting as supplement to a diet based on wheat bran available in this village close to town.

An experimental forage bank was established on 1.5 hectare planted with seven different browse species following a random block design with 3 replicates. Each individual plot was $625m^2$, and the browses were planted 1x1m apart. Seeds were collected and grown in nurseries. But only five of the seven species (*Bauhinia rufescens, Kigelia africana, Leucena leucocephala Ziziphus mauritiana* and *Prosopis africana*) had seedlings sufficiently developed and in large numbers to be fully planted. *Maerua crassifolia* seedlings were too small and had to be kept in the nursery for another year. *Gliricidia sepium* suffered from insect attacks. For those seedlings planted, survival and size of the shrub 4 months after replanting were measured for the five species (table 90).

**Table 90**. Rate of survival and height of shrubs four months after planting in Niger.

| Shrub species | Survival (%) | Heigth (cm) |
|---|---|---|
| *Bauhinia rufescens* | 95 | 43 |
| *Kigelia africana* | 99 | 27 |
| *Leucena leucocephala* | 84 | 59 |
| *Ziziphus mauritiana* | 86 | 33 |
| *Prosopis africana* | 87 | 32 |

Rates of plant survival 17 month after plantation were 91.2, 94.3, 75.7 and 45.5% respectively. Their growth performance differed markedly with Ziziphus and Bauhinia surpassing Prosopis and Kigelia in height growth (table 91). Ziziphus was also the more productive in terms of foliage, followed by Prosopis, although the growth of Prosopis was very unequal from block to block. Kigelia and Bauhinia yielded much less.

**Table 91**. Rate of survival, height, annual height growth, foliage production (fresh and dry) 17 months after plantation of four woody plants grown in a fodder bank in N'Dounga, Niger.

| | Survival rate | Height | Annual growth | Fresh leaf mass | Leaf dry mass |
|---|---|---|---|---|---|
| | % | cm | cm | (kg ha$^{-1}$) | (kg ha$^{-1}$) |
| *Bauhinia rufescens* | 91.2 | 114.0 (19.5) | 60.1 (4.6) | 675.0 | 166.7 |
| *Kigelia africana* | 94.3 | 21.1(5.1) | 5.4 (4.8) | 400.0 (58.3) | 191.7 (14.4) |
| *Ziziphus mauritiana* | 75.8 | 103.1(22.2) | 60.2 (16.4) | 705.5 (208.4) | 405.6 (117.1) |
| *Prosopis africana* | 45.5 | - | 19.7 | 629.2 (830.8) | 329.3 (441.9) |

Associated with the agroforestry trial, a preliminary test was carried out in N'Dounga, in the Niger river valley, to feed 8 sheep (4 for per browse species) with foliages of two of the browse species planted 17 month earlier in a forage bank stand. The energy requirement of the sheep were covered by 700 g of wheat bran given every day. Results of the preliminary test carried out in N'Dounga on the use of browses in fattening diet for sheep, the intake of leaves of *Bauhinia rufescens and Kigelia africana* was high with mean intake of 1036 g d$^{-1}$ per animal or 76.46 g kgPV$^{-0.75}$ d$^{-1}$ which is comparable to intake of highly digestible and protein rich feed such as cowpea or groundnut haulms or else *Alysicarpus ovalifolius* hay (table 92). Moreover, the liveweight gains were comparable to the performances of sheep fattened with wheat bran and cowpea or groundnut haulms.

**Table 92.** Mean daily intake of browses given ad libitum to sheep fed 700 g d$^{-1}$ of wheat bran and resulting mean weight gains.

| Performance per sheep | Browse species | | |
|---|---|---|---|
| | *Bauhinia rufescens* | *Kigelia africana* | Mean(sd) |
| Intake g d$^{-1}$ sheep$^{-1}$ | 921.11 ± 293.08 | 1130.66± 209.79 | 1035.86 ±270.49 |
| Intake g kg PV$^{-0.75}$ d$^{-1}$ | 71.11± 22.18 | 80.87 ±14.02 | 76.46 ±18.70 |
| Weight gain g d$^{-1}$ | 121.4 ± 30.3 | 197.5 ± 31.8 | 159.5 ± 15.5 |
| Manure yield g d$^{-1}$ | 619.3 ± 96.5 | 6 39 ± 39.4 | 619.2 ± 14.7 |

## 4.5. Discussion and ex-post economic assessments

Ex-post economic assessment of soil amendment with P-enriched compost for irrigated rice

The calculation of benefits and marginal rates of returns of the substitution of inorganic fertilizer by compost enriched with rock phosphate indicated a large opportunity for productivity gain and profits (table 93). And yet, these calculations do not include the expectable residual effect of compost application on soil fertility which should be measured (effect on soil organic matter, soil acidity, and P availability to plants.

The adoption could depend on the labor cost implied by the compost making (digging of pits, watering the compost, manipulations, transportation and application on the land) which are not fully included in the assessment. Research should target the best ways to reduce these costs and efforts.

**Table 93**: Ex-post economic assessment of the use of compost diversely enriched in phosphorus by incorporation of local rock phosphate (Kirkissoye, 2001)

| Parameters per hectare or irrigated rice | Urea + NPK | 6t Compost | 6t Compost + 4% RP | 6t Compost + 8% RP | 6t Compost + 12% RP | 6t Compost + 16% RP |
|---|---|---|---|---|---|---|
| Grain yield (kg) | 3800 | 5450 | 6750 | 6750 | 6750 | 7100 |
| Straw yield (kg) | 7350 | 8670 | 6550 | 6640 | 7610 | 7450 |
| **Gross product (CFA)** | **462000** | **660000** | **816000** | **816000** | **816000** | **858000** |
| Seeds (CFA) | 86000 | 86000 | 86000 | 86000 | 86000 | 86000 |
| Fertilizer cost (CFA) | 75000 | 63750 | 71750 | 79750 | 87750 | 95750 |
| Labour cost (CFA) | 194000 | 203500 | 203500 | 203500 | 203500 | 203500 |
| **Total variable costs (CFA)** | **345000** | **353250** | **361250** | **369250** | **377250** | **385250** |
| Net benefit (CFA) | 117000 | 306750 | 454750 | 355750 | 438750 | 472750 |
| Marginal rate of return (%) | NA | 2300 | 2078 | 985 | 998 | 884 |

<u>Ex-post economic assessment of alternative diets for dairy cows in peri-urban Niamey</u>.
The milk yields, and thus revenue from the dairy cows were superior than planned by the ex-ante assessment but the contrast between improved treatments and the control treatment were not as high as expected explaining for the more modest marginal rates of returns on additional inputs (Table 93b).

**Table 93b**. Ex-post marginal analysis of alternative cow supplement feed in peri-urban area of Niamey, Niger.

| Technical and economic parameters | Treatments | | |
|---|---|---|---|
| | Control: Rice straw ad libitum + wheat bran + salt | Rice straw 7 kg $d^{-1}$ + wheat bran 1.5 kg $d^{-1}$ + brewer's waste 1kg $d^{-1}$ | Rice straw 7 kg $d^{-1}$ + wheat bran 2 kg $d^{-1}$ + brewer's waste 1 kg $d^{-1}$ |
| Milk yield litres $cow^{-1}$ $d^{-1}$ | 1.5 | 3.5 | 4.5 |
| Manure yield kg $d^{-1}$ | 5 | 5 | 4 |
| **Gross product (CFA)** | **550** | **750** | **945** |
| Labor cost (CFA) | 25 | 25 | 25 |
| Input cost (CFA) | 195 | 290 | 332 |
| **Total cost (CFA)** | **220** | **315** | **357** |
| Net benefit (CFA) | 330 | 435 | 588 |
| Marginal rate of return (%) | - | 110 | 188 |

<u>Ex-post economic assessment of alternative diets to fatten steers in peri-urban Niamey</u>.
The weight gain performance were inferior to the expected with increased supplements of wheat bran, and on the contrary the performance of the farmer practice control were superior to expected. As a consequence the alternative diets were still beneficiary but the rate of returns for the additional input in supplement was more modest than estimated in the ex-ante analysis (Table 93c).

**Table 93c**. Ex-post marginal analysis of alternative diets to fatten young steers in peri-urban area of Niamey, Niger.

| Technical and economic parameters calculated for a 90 days fattening period. | Treatments | | |
|---|---|---|---|
| | Control: Rice straw ad libitum + 1.5 kg $d^{-1}$ wheat bran + urea lick | Rice straw ad libitum + wheat bran 2.5 kg $d^{-1}$ + urea lick | Rice straw ad libitum + wheat bran 3 kg $d^{-1}$ + urea lick |
| Weight gains $steer^{-1}$ $d^{-1}$ | 32 | 39 | 47 |
| Manure yield kg $d^{-90}$ | 209 | 217 | 256 |
| **Gross product (CFA)** | **19941** | **23880** | **28717** |
| Labor cost (CFA) | 2250 | 2250 | 2250 |
| Input cost (CFA) | 12960 | 15030 | 19170 |
| **Total variable cost (CFA)** | **15210** | **17280** | **21420** |
| Net benefit (CFA) | 2661 | 6600 | 7297 |
| Marginal rate of return (%) | Ref | 190 | 75 |

### 4.6. Pathways for diffusion and adoption

The diffusion and adoption pathways do not differ from the one adopted in the rest of the country in the rainfed benchmark sites. However, the strength of the cooperative society in Kirkissoye and the proximity of the research stations at Kollo and Sadoré offer additional opportunity for information exchange with farmers. Also, demonstration trials, open days and farmers' visits were organized. Government Ministers, development agencies, and donor agencies represented in Niamey attended the open days. Technical recommendations were discussed at fora organized by the ministries and have been summarized in easy to read pamphlets.

## 5. Sites in Sénégal
### 5.1. Farming systems and benchmark sites in Senegal

In Senegal, the benchmark site was located in the northern and drier part of the 'groundnut belt' of Senegal, in the district of Diourbel. Four villages were selected within an IFAD funded agroforestry project that has been active and willing to collaborate. The four villages were selected for their contrasted crop-livestock situations and development histories. Due to the relatively high population density and the long history of nutrient mining by groundnut cultivation, farmers in this area are facing severe soil fertility problems which affects the productivity of the whole agricultural system. Diagnostics were established through group interviews, problem tree, technology ranking, farm ranking and village land mapping and transects. The group interviews in the village were completed by interviews of elected representatives, and administrative and technical service officers. Participatory surveys provided a detailed description of the farming systems, resource management practices and institutions. Farm-households have been classified in 3 to 4 classes of wealth as perceived by the farmers themselves (table 94) The initial and participatory analysis of theses data established a diagnostic used to guide recommendations (Sylla 1999; Dia et al. 1999).

It appears that because of increased population density and crop expansion close to saturation, the role of livestock in farmer economy and conservation of soil fertility is declining. This is indicated by the low and decreasing average livestock endowment of farmers (table 2), and also by important changes in relations with other communities, especially transhumant pastoralists (table 95).

**Table 94**. Average resource endowments by class category in study villages in the Diourbel benchmark site. The area cropped is expressed in percent of the farm land. Labor hired is expressed in proportion of farm employing hired laborers.

| *Villages* | *Category* | *Number of farm* | *Labor hired (%)* | *Area Cropped (land %)* | *Cattle (head)* | *Sheep (head)* | *Goats (head)* | *Nature of the development Project* |
|---|---|---|---|---|---|---|---|---|
| Kane-Kane | High | 16 | 42 | 69 | 6 | 22 | 27 | PAGF* supporting farmer managed sheep fattening schemes (credit with CNCAS**) |
| | Medium | 29 | 31 | 92 | | 9 | 10 | |
| | Low | 55 | 18 | 71 | | 2 | 3 | |
| Keur Sègue | High | 19 | 0 | 85 | 6 | 10 | 12 | |
| | Medium | 52 | 0 | 95 | | 7 | 7 | |
| | Low | 29 | 0 | 95 | | 2 | 2 | |
| Loumène | High | 14 | 27 | 95 | 2 | 4 | 14 | |
| | Medium | 22 | 0 | 95 | | 2 | 7 | |
| | Low | 41 | 0 | 95 | | 2 | 5 | |
| | Very low | 22 | 0 | 95 | | 2 | 5 | |
| Mbari Ndondol | High | 14 | 0 | 88 | 8 | 3 | 9 | CARITAS funded project to support GIE*** |
| | Medium | 36 | 0 | 71 | | 3 | 8 | |
| | Low | 30 | 0 | 90 | | 5 | 13 | |
| | Very low | 20 | 0 | 89 | | 2 | 4 | |

* Projet Agro-Forestier de Diourbel (IFAD funded )
** CNCAS Caisse Nationale de Crédit Agricole au Sénégal
*** Groupement d'Interet Economique

**Table 95**. Average number of head of cattle sheep and goats either kept sedentary in the village or sent periodically in transhumance by farm-households sampled in four villages of the Senegal ground nut belt.

| Villages | Cattle | | Sheep | | goats | |
|---|---|---|---|---|---|---|
| | Sedentary | mobile | Sedentary | Mobile | Sedentary | mobile |
| Bari Ndondol | 4 | 2 | 8 | 0 | 9 | 0 |
| Kane Kane | 2 | 4 | 8 | 1 | 11 | 0 |
| Keur Ségue | 4 | 2 | 8 | 0 | 9 | 0 |
| Loumène | 2 | 0 | 3 | 0 | 10 | 0 |

The climate of the northern part of Senegal groundnut belt is Salelian with 20 to 50 days of rain in summer, and irregular annual rainfall between 300 and 500 mm. The soils developed on the sandy quaternary sediments are classified by the farmers as ‘dior’, ferrugineous leached for the more sandy, ‘deck-dior’ less leached and slightly more clayed, and ‘deck’ for the loamy-clayed soil waterlogged of the valleys. The natural vegetation was an open savanna, with an herbaceous layer dominated by annual grasses and scattered trees and shrubs among which spiny Acacias and Balanites, but also Combretaceae such as Guiera senegalensis and Combretum glutinosum, and the emblematic Baobab. However, most of the lands have been cleared and cropped for long. The rural population in this district was domiated by the Serer who have a long tradition of crop-livestock farming system, and also by minorities of Wolof and Fulani.

The farming systems in the Diourbel region is based on crop rotation: millet as the staple food is rotated with groundnut, a cash crop, followed by a fallow period to restore soil fertility and provide forage to livestock. Sorrel, cowpea and water-melon are the main secondary crops. However, with expansion in crop area caused by a steady population growth in a region already densely populated, the area of land left in fallow has been drastically reduced. Since the use of inorganic fertilizer is very limited, soil fertility has declined. The reduction in the area under fallow has also reduced forage resources available to livestock, especially during the wet season, forcing the animals to go on transhumance, thus, reducing the role of livestock in organic matter and nutrient recycling within the village agro-ecosystem (table 96). Because of the cash-crop economy based on groundnut, farmers generally use animal traction and are relatively well equipped in carts (51% of farms possess at least one) and tillage equipment (73% of farms are equipped with a seeder, 64% with a plough, and 41% with a groundnut lifter).

**Table 96**: Mode of manure application depending of villages.

| Village | Mode of manure application in % of farms | |
|---|---|---|
| | Collection, transport and hand spreading | Corralling animals |
| Bari Ndondol | 65 | 35 |
| Loumène | 100 | 0 |
| Keur Sègue | 81 | 19 |
| Kane-kane | 70 | 30 |

The access to cropland is regulated by customary rights but land is in the process of being privatized. Households in the study villages, except in Mbari Ndondol, appear to be equally distributed among the three wealth categories established and there is not much contrast between wealth groups in their declared success in satisfying food consumption needs from own-farm production (Table 97). None of the wealth groups, including the better off, considered that own-farm production could cover more than two-thirds of household food consumption needs, indicating pervasive poverty in the benchmark area.

**Table 97**. Distribution of households by wealth category and food self-sufficiency in the study sites in Senegal, 2000.

| | Villages | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Kane-kane | | Keur Sègue | | Loumène | | Mbari Ndondol | |
| Wealth category | % of farm house-holds | Food self-sufficiency (months) | % of farm house-holds | Food self-sufficiency (months) | % of farm house-holds | Food self-sufficiency (months) | % of farm house holds | Food self-sufficiency (months) |
| High | 30 | 8 | 30 | 7 | 30 | 8 | 20 | 8 |
| Medium | 35 | 7 | 50 | 8 | 30 | 8 | 30 | 7 |
| Low | 35 | 6 | 20 | 8 | 40 | 8 | 50 | 7 |

Farmers identify crops as main economic activity (60%) followed by house care (17%) and animal fattening (7%). Livestock husbandry is the most frequently quoted as secondary economic activity. Seasonal mobility of population remain an exception (10%).

### 5.2. Technological options for more efficient crop-livestock integration

The decline in soil fertility is perceived as a major constraint to crop production. Although fallowing and N-fixation by *Acacia albida* trees are recognized as important mechanisms for improving soil fertility, crop expansion will reduce the impact of these options. Due to the high cost of inorganic fertilizer, crop rotation and application of manure and compost appear to represent viable alternatives to poor farmers. These options are already widely used by farmers (Table 98). Compost enriched with locally available rock phosphate together with strategic supplementation of cattle using readily available groundnut haulms, millet bran, cotton cakes and urea were some of the new interventions evaluated at this benchmark site. Part of the objective was to maintain enough livestock in the system, for milk and meat production and also as sources of manure. To achieve this objective in the context of a reduction of grazing resources, feed supplementation at the end of the dry season will be increasingly required. Strategic mineral supplementation could improve the use efficiency of poor quality feed such as millet stalks and at the same time enhance the nutrient content of the excretions. In addition, a small fodder bank, in the form of browse species was also tested as an option for improving the protein and nutrient content of late dry season feed for goats.

**Table 98**. Methods of soil fertility maintenance by wealth category in the study villages in Senegal, 2000.

| | Proportion (%) of households in each wealth category using following method | | | |
|---|---|---|---|---|
| Wealth category | Fallowing / N-Fixation by Acacia | Crop rotation | Manure / Compost | Inorganic Fertilizer |
| High | 20.2 | 21.2 | 47.6 | 7.8 |
| Medium | 30.4 | 28.1 | 39.2 | 2.3 |
| Low | 27.0 | 25.8 | 43.4 | 3.8 |
| All | 26.5 | 26.0 | 43.3 | 4.2 |

### 5.3. Ex-ante economic impact assessment.

In a participatory ex-ante assessment of variable costs of main agriculture activities farmers have not included labour cost nor the cost of credit. Variable costs for cropping were estimated at 7560 CFA per hectare and per year while cost of fattening was estimated at 32570 (table 99). In the case of fattening the cost of credit come close to half of the gross margin (Ndione 1990).

**Table 99**: Estimates of total variable costs and net benefit of two main economic activities (CFA per ha or per head).

| | Total variable cost | | Net Benefit | |
|---|---|---|---|---|
| Village | Crop | Fattening | Crop | Fattening |
| Keur ibra Diop | 12319 | 32500! | 54795 | 257750! |
| Mbarry aly Ndiaye | 3600 | 29000 | 29565 | 218330 |
| Mbarry gouye Tann | 9740 | 49438 | 52455 | 321875 |
| Keur Seck | 2628 | 49438 | 30115 | 184000 |
| Sylla Dappa | 10250 | - | 62260 | - |
| Thiakhene | 6250 | 23542 | 119305 | 93835 |
| Kan kan | 12140 | 26841 | 75660 | 128920 |
| Sarene Mouride | 3535 | 17200 | 56670 | 84400 |
| Mean | 7558 | 32566 | 60103 | 184160 |
| Maximum | 12319 | 48340 | - | - |

! Excluding labour cost

### 5.4 Project implementation, trials and results

Among the four villages of the benchmark site, crop and livestock trials were conducted in the village of Kane-Kane where an adequate resident livestock population exists. In 1999 and 2000, crop experiments and feeding trials were also conducted on station at Bambey. In addition, a survey was conducted to determine the feed quality of indigenous and introduced woody plants at Sébikotane in 1999 and followed by agroforestry trial conducted in the forest of Bandia in 2000.

<u>Mineral supplementation of cattle with cotton seeds, urea, and/or rock phosphate</u>
Fifty-eight cattle belonging to farmers in the village of Kane-Kane (Diourbel district) were used in an on farm feed supplementation trial. The packages included 75g of Thiès rock phosphate diluted in 30 liters of drinking water (treatment P); 500g of millet stover treated with urea (4 %) plus 1 kg of groundnut cake plus 800g of millet bran (treatment N); or combination of these two treatments (Treatment PN) were compared to a control treatment comprising of animals that were not supplemented. The effects of the treatments were assessed on changes in cattle condition score, body weight, milk yield and on the quantity and chemical composition of feces.

In the on-farm trial conducted Kane-Kane, the interpretation of the results of the cattle mineral supplementation was not easy because a mixture of male and female cattle of different ages were used, impact was assessed through condition scoring and weighing (Table 100). As expected in the dry season, the average score of cattle in the control lot decreased, while the score remained unchanged for cattle supplemented with phosphorus and increased slightly for cattle supplemented with N or N and P. Manure collected per animal ranged between 162 to 187 kg per animal over the 4 month period, averaging 1.35 and 1.56 kg DM

$d^{-1}$ per animal. The content of N, P and K in the feces reflected the supplementation given to the animals (Table 101).

**Table 100.** Effects of on-farm cattle supplementation trials on cattle condition score and fecal output, Kane-Kane, Senegal, 2000.

| Treatment | n | Condition score | | Weight (kg) | | | Fecal production (kg) | |
|---|---|---|---|---|---|---|---|---|
| | | At onset | 4 month later | At onset | 4 month later | GMQ (g/d) | Per animal | Per herd |
| Control | 3 | 3.6 | 2.7 | 265.0 | 273.1 | 72 | 183 | 2740 |
| P | 3 | 3.5 | 3.5 | 283.7 | 296.0 | 110 | 162 | 1779 |
| N | 3 | 2.8 | 3.5 | 238.0 | 272.3 | 306 | 172 | 2746 |
| PN | 4 | 3.1 | 4.0 | 194.3 | 239.3 | 402 | 187 | 2989 |

**Table 101.** Effects of on-farm cattle supplementation trials on nutrient content of feces, Kane-Kane, Senegal, 2000.

| Treatment | N (%) | | P (%) | | K (%) | |
|---|---|---|---|---|---|---|
| | March | June | March | June | March | June |
| No supplement | 1.35 | 1.15 | 1.10 | 1.20 | 0.22 | 0.25 |
| P | 1.33 | 1.28 | 1.27 | 1.63 | 0.26 | 0.23 |
| N | 1.45 | 1.31 | 1.21 | 1.28 | 0.23 | 0.24 |
| PN | 1.44 | 1.88 | 1.20 | 1.48 | 0.24 | 0.31 |

The on-farm trial in Kane-Kane was complemented by a feeding trial was carried out on station at Bambey to assess the influence of mineral supplementation with urea, cotton cakes and rock phosphates on the performance of cattle and their recycling of minerals. Four diet supplementation packages (Table 102) were tested and compared to a non-supplemented control fed sole groundnut haulms. The feeding trial was conducted over 70 days from April to July, on 40 bulls, 1 to 4 years old, grouped in 5 lots of 8 animals. The average initial weight was 222 kg live-weight and animals were weighed three times during the trial, while feeds were sampled twice and feces seven times. The bulls fed various combinations of cotton seed cake and 3-calcium phosphate in addition to groundnut haulms, *ad libitum*, performed worse than the control animals fed only groundnut haulms which gained 245 g LW $d^{-1}$ (Table 102). This unexpected result was apparently due to diarrhea caused by the phosphate that the animals tended to refuse. Fecal production was equally affected, with a maximum of 10.9 g $d^{-1}$ for the control. However N, P and Ca contents in the feces reflected the composition of the supplements.

**Table 102**. Effects of on-station cattle supplementation trials on daily live weight gains and fecal production, Bambey, Senegal, 2000.

| Treatment | Live weight gain (g $d^{-1}$) | Fecal production (kg fresh weight $d^{-1}$) |
|---|---|---|
| No supplement | +245 | 10.9 |
| NP | -53 | 7.9 |
| 2NP | +50 | 8.7 |
| N2P | -11 | 7.0 |
| 2N3P | -87 | 7.8 |

<u>Application of manure from variously supplemented cows on a millet-groundnut rotation</u>

In 2000, an on-farm soil fertility trial linked to a trial on cattle supplementation was conducted with 12 farmers in the village of Kane-Kane. The design was a full block with 2 to

3 treatment replicates depending on the size of the farmer's field. There were five treatments, a control with no manure and four treatments with 4t manure ha$^{-1}$ differing by the quality of the manure, which was related to the feeding regime of the cattle. In the first treatment, cattle were not supplemented; in the second, they received 75 g of 3-calcium phosphate per day; in the third, 500g of millet stover treated with urea (4 %), plus 1kg of peanut cake and 800g of millet bran per day; and in the last, they received both phosphate and nitrogen-rich supplements. Samples of manure were analyzed to assess the effects of different treatments and soil samples were also taken. Millet growth was monitored and yields measured in panicles, grains and stalks. In this experiment, manure was applied every second year, and the effect measured on millet grown the first year and groundnut grown in the second year.

Feed supplementation of cattle with various combinations of cotton seed and 3-calcium phosphate was reflected in the nutrient content of feces (Table 103). There were no significant differences in K across treatments. The no and low supplement treatments had significantly lower N and Ca content than other treatments, while cattle fed no supplements had P content in feces significantly lower than all supplemented cattle.

**Table 103**. Effect of on-station cattle supplementation trials with various combinations of cotton seed and 3-calcium phosphate on the concentrations of N, P, K and Ca in feces, Bambey, Senegal, 2000.

| Treatments | Nutrient concentration in feces (%) | | | |
|---|---|---|---|---|
| | N | P | K | Ca |
| No supplement | 1.506 | 0.165 | 1.997 | 1.434 |
| NP | 1.511 | 0.527 | 2.102 | 1.595 |
| 2NP | 1.607 | 0.579 | 2.758 | 2.111 |
| N2P | 1.677 | 0.620 | 1.390 | 2.141 |
| 2N3P | 1.681 | 0.614 | 1.749 | 1.938 |
| LSD | 0.060 | 0.178 | 0.870 | 0.300 |

Effects of application of 2 t ha$^{-1}$ of manure and of manure quality on millet and groundnut yields were generally not significant (Table 104), in spite of quite large differences in millet yields between the control without manure and the treatment with 20% cotton seed and 100g of phosphate per day (i.e., 528 kg ha$^{-1}$ and 1406 kg ha$^{-1}$ millet grains and stalks, respectively). Yield differences for groundnut were very modest, with 140 and 620 kg ha$^{-1}$ of pods and haulms, respectively.

**Table 104**. Effects of the application of 2t ha$^{-1}$ manure produced by cattle supplemented with various combinations of cotton seed and 3-calcium phosphate on the yield of millet and groundnut, Bambey, Senegal, 2000.

| Treatment | Millet yield (kg ha$^{-1}$) | | Groundnut yield (kg ha$^{-1}$) | |
|---|---|---|---|---|
| | Grains | Stalks | Pods | Haulms |
| No manure | 1482 | 3579 | 774 | 1386 |
| No supplement | 1878 | 4072 | 696 | 1251 |
| NP | 1456 | 3634 | 824 | 1263 |
| 2NP | 2010 | 4985 | 836 | 1871 |
| N2P | 1784 | 4200 | 766 | 1332 |
| 2N3P | 1860 | 3908 | 726 | 1818 |
| LSD | 615 | 1090 | 219 | 742 |

On-farm manure application trials confirmed the impact of livestock diet on the nutrient content of the manure and thus on the nutrients added to the soil. Depending on the livestock diet, nutrients added to the soil ranged from 50.0 to 66.4 kg N $ha^{-1}$, 105.3 to 132.8 kg $P_2O_5$ $ha^{-1}$, and 11.3 to 13.3 kg $K_2O$ $ha^{-1}$. Treatments had no effect on the density of hill at harvest nor on grain weight but had highly significant effect on the grain and stalk yields, number of tiller and panicle per hill (Table 105). Compared to the yield of plots manured by un-supplemented animals, the gain in grain yield due to manure of cattle supplemented in N and P (i.e., 264 kg $ha^{-1}$) was more than the sum of the gains due supplementation either in N (92 kg $ha^{-1}$) or P (73 kg $ha^{-1}$).

**Table 105**. Effects of on-farm cattle supplementation and manuring trials on millet (Souna3) grain yield and grain weight, Kane-Kane, Senegal, 2000.

| Treatments | Grain yield | Weight of 1000 grains |
|---|---|---|
| | Kg $ha^{-1}$ | g |
| Control with no manure | 599 | 8.03 |
| 4t manure $ha^{-1}$ from un-supplemented cattle | 744 | 8.14 |
| 4t manure $ha^{-1}$ from cattle supplemented with P | 817 | 8.31 |
| 4t manure $ha^{-1}$ from cattle supplemented with N | 836 | 8.08 |
| 4t manure $ha^{-1}$ from cattle supplemented with N and P | 1008 | 8.33 |

In 2001, the residual effect of a manuring trial initiated in 2000 on millet was measured on groundnut crop considering a millet-groundnut rotation system. The pattern of millet-groundnut rotation allowed 8 replications of the trial (Table 106).

**Table 106:** Farmers and hamlet of the village of Kane-Kane in which manure trials were conducted in 2000 (millet) and 2001 (groundnut)

| Hamlets | Farmers names | |
|---|---|---|
| | 2000 millet crop | 2001 ground nut crop |
| Kondié | Birane DIOP | - |
| | Diab DIOUF | Diab DIOUF |
| | Saliou KANE | Saliou KANE |
| | Ndiouga | Ndiouga |
| | Bada KANE | Bada KANE |
| | Modou KANE | Modou KANE |
| Keur Sogui | Malick SARR | Malick SARR |
| Keur Yambou | Ngagne Kane Ndiack | - |
| Thiokhème | Ndiouga KANE | - |
| | Abdou Kane DIAP | Abdou Kane DIAP |
| | Omar DIALLO | - |
| | Aliou GUEYE | Aliou GUEYE |

The design was a full block with 2 to 3 treatment replicates depending on the size of the farmer's field. There were five treatments, a control with no manure and four treatments with 4t manure $ha^{-1}$ differing by the quality of the manure, which was related to the feeding regime of the cattle. In the first treatment, cattle were not supplemented; in the second, they received 75 g of 3-calcium phosphate per day; in the third, 500g of millet stover treated with urea (4 %), plus 1kg of peanut cake and 800g of millet bran per day; and in the last, they received both phosphate and nitrogen-rich supplements. Samples of manure were analyzed to assess the effects of different treatments and soil samples were also taken (Table 107). These differences in nutrient content resulted in differences in nutrients inputs ranging from 50.0 to 66.4 kg N $ha^{-1}$, 105.3 to 132.8 kg $P_2O_5$ $ha^{-1}$, and 11.3 to 13.3 kg $K_2O$ $ha^{-1}$.

**Table 107**. Organic matter and mineral contents of cattle feces fed different supplements: non supplemented control, N supplemented with 500g of millet stover treated with urea (4 %), plus 1kg of peanut cake and 800g of millet bran per day, P supplemented with 75 g of 3-calcium phosphate per day; and combination of N and P supplements.

| Treatments | Dry matter (%) | Minerals (%) | O.M. (%) | Protein (%) | N (%) | P (%) | K (%) |
|---|---|---|---|---|---|---|---|
| control | 92,2 | 23,1 | 76,8 | 7,19 | 1,15 | 0.25 | 1,20 |
| N suppl. | 91,4 | 16,9 | 83,1 | 8,20 | 1,31 | 0.24 | 1,28 |
| P suppl. | 91,4 | 16,9 | 83,1 | 8,20 | 1,31 | 0.24 | 1,28 |
| N + P suppl. | 90,7 | 19,1 | 80,9 | 11,70 | 1,88 | 0.31 | 1,48 |

In 2001, the residual effect of manuring treatments was measured on a groundnut crop which germination was fine and was not affected by the manuring nor by the quality of manure applied in 2000 (table 108). However, plant density decreased in all treatments during the development of the crop mainly due to infections with *Aspergilus niger* et *Macrophomina sp.*

**Table 108**: Groundnut plant density at the 28 day after sowing (DAS) and at the harvest as a function of manuring and manure quality (averages of all farmers fields)

| Treatments | Density at 28 DAS (plants / ha) | Density at harvest (plants / ha) |
|---|---|---|
| Control with no manure | 120210 | 88467 |
| Manure of unsupplemented cows | 123472 | 91867 |
| Manure of cows supplemented in N | 118518 | 91200 |
| Manure of cows supplemented in P | 119280 | 86200 |
| Manure of cows supplemented in N + P | 120634 | 89000 |
| Mean | 120224 | 89347 |
| CV (%) | 8,67 | 12.82 |
| F Test ( P = 0,05) | NS | NS |

NS = non significant

Plant above soil mass measured 52 days after sowing did not differ with treatments nor pod density (table 109). However leave density and plant highth were higher with manure from N supplemented cows.

**Table 109**: Ground nut plant dry matter, number of leaves and higth of the plant at 52 day after sowing harvest as a function of manuring and manure quality (averages of all farmers fields)

| Treatments | Plant Dry matter (g / plot) | Leaves density (/plant) | Pods density (/plant) | Plant highth (cm) |
|---|---|---|---|---|
| Control with no manure | 49,06 | 51,93 | 7,24 | 19,09 |
| Manure of unsupplemented cows | 51,57 | 51,80 | 7,44 | 20,79 |
| Manure of cows supplemented in N | 57,39 | 58,75 | 7,79 | 20,27 |
| Manure of cows supplemented in P | 48,63 | 52,56 | 7,29 | 20,16 |
| Manure of cows supplemented in N + P | 56,89 | 57,55 | 8,01 | 21,24 |
| Mean | 52,71 | 54,52 | 7,55 | 20,31 |
| CV (%) | 28,74 | 27,17 | 38,86 | 15,14 |
| F Test ( P = 0,05) | NS | S | NS | S |

NS = non significant ; S = significant at P = 0.05

**Table 110**: Residual effect of the application of manure from cattle supplemented or not with N and/or with P on groundnut (var. Fleur11) crop at harvest.

| Treatments | Pod density (/ ha) | Bean density (/ ha) | Weight of 100 beans (g) |
|---|---|---|---|
| Control with no manure | 999867 b | 1529933 b | 59.100 |
| Manure of unsupplemented cows | 1069467 ab | 1627533ab | 61.880 |
| Manure of cows supplemented in N | 1263733 a | 1903000 a | 61.887 |
| Manure of cows supplemented in P | 1121467 ab | 1794667 ab | 61.460 |
| Manure of cows supplemented in N + P | 1194200 ab | 1957867 a | 63.007 |
| Mean | 1129747 | 1762600 | 61.467 |
| Mean standart error . | 55495 | 90269 | 1..273 |
| CV (%) | 19.02 | 19..83 | 8.02 |
| F test at P= 0,05 | S | S | NS |

At harvest, both pod and bean densities were increased by the use of manure from N or N+P supplemented cows while the weight of the beans was not affected by the manuring treatments (Table 110). Across treatment average yields were 2090, 1341 and 776 kg / ha, for haulms, pods and beans respectively (table 111). The yields in plots manured and cropped in millet last year were superior to the yields of non manured nor cropped plots. The best yields were obtained with manure from cows supplemented N or N and P, with a difference to the control without manure of 400 kg haulms / ha (+21 %), 350 kg pods / ha (+30 %) and 174 kg beans/ ha (+25 %).

**Table 111:** Residual effect of the application of manure from cattle supplemented or not with N and/or with P on groundnut (var. Fleur11) yields.

| Treatments | Haulms (kg / ha) | Pods (kg / ha) | Beans (kg/ ha) |
|---|---|---|---|
| Control with no manure | 1863 c | 1163 b | 683 b |
| Manure of unsupplemented cows | 1947 bc | 1253 ab | 742 ab |
| Manure of cows supplemented in N | 2263 a | 1513 a | 857 a |
| Manure of cows supplemented in P | 2137 abc | 1287 ab | 756 ab |
| Manure of cows supplemented in N + P | 2240 ab | 1353 ab | 842 ab |
| Mean | 2090 | 1341 | 776 |
| Mean standart error . | 1056 | 70 | 42 |
| CV (%) | 19.56 | 20.68 | 20.99 |
| F test at P= 0,05 | S | S | S |

The on-farm trial was complemented by an on-station trial at Bambey. This trial was duplicated on millet (IBV-8004) and groundnut (55-437) in pure stands, with 6 treatments and four replicates (Fisher blocks). The treatments consisted of applying 2 t $ha^{-1}$ of manure of cattle that have received various combinations of cotton seed cake and 3-calcium phosphate to supplement a basic diet of groundnut haulms (Table 112).

Feed intake and cattle fecal excretion were measured, and nutrient contents of feces and soil samples were analyzed prior to manual broadcast of manure. Millet and groundnut growth were monitored, yields measured and sub-sampled to analyze nutrient export (table 104).

**Table 112.** On-station manuring and cattle supplementation trials, Bambey, Senegal 2000.

| Treatment | Manure application | Feeding regime of the cattle used to produce manure | | |
|---|---|---|---|---|
| | | Groundnut haulm | Cotton seeds | 3-calcium phosphate |
| | t $ha^{-1}$ | | % MS | g |
| No manure | 0 | - | - | - |
| No supplement | 2 | Ad libitum | 0 | 0 |
| NP | 2 | Ad libitum | 15 | 100 |
| 2NP | 2 | Ad libitum | 20 | 100 |
| N2P | 2 | Ad libitum | 15 | 150 |
| 2N3P | 2 | Ad libitum | 20 | 200 |

Supplementation of small ruminant diets with browses

In 1999, the feed value of some Sahelian browses species were evaluated depending on pruning methods, mode of forage conservation and of integration in the animal diet targeting given level of animal production. The cell wall concentration in studied species were compatible with good feed digestibility in ruminants; however, Calotropis procera had the lowest NDF content, Leucaena leucocephala had the highest crude protein level while Adansonia digitata appeared to be a good source of calcium and phosphorus. For the studied species, early dry season seems to be the best period for harvesting good quality forage as it corresponded to highest phosphorus and protein concentration. High tannins content are still within the tolerable level (< 5%) and do not have detrimental effect on digestibility. The impact of cutting frequency and height on survival rate, growth and forage quality would suggest moderate exploitation of tree forages. Conservation methods globally influenced ($P<0.01$) forage quality. Air drying (at sun or indoor) didn't modify plant nutritive value and should be promoted on farm. Studies of the influence of the proportion of browses in the diet have put in evidence the occurrence of digestive interactions phenomena suggesting limits in ruminant diets. Recommended levels were 15, 15, 30, 50 % for Guiera senegalensis leaves, Faidherbia albida pods, Adansonia digitata, Pitecellobium dulce and Calotropis procera leaves respectively.

A agroforestry trial was conducted in Bandia to assess the response to cutting treatments of two shrubs species with highly nutritive fodder, *Bauhinia rufescens* and *Prosopis africana*, planted in groves in 1991 at the Bandia research station. The design was a 2 x 2 x 3 factorial arrangement of, shrub species, height of cutting (0.5 or 1 m), and season of cutting (July, November, March). Treatment effects were measured on plant survival, growth (in height and stem diameter), branching, foliage production and biochemical composition. The results of the browse cutting trial indicated that none of the *Prosopis* died following a cut in July at 1 m high, while 20% died following a 0.5 m cut. For Bauhinia, 20% of the shrubs died following the cut irrespective of its height. Coppices grew faster for *Prosopis*, and following the cut at 1 m.

### 5.5. Discussion and ex-post economic assessment

Mineral supplementation (with urea and phosphate) of cattle

In the on-farm trials carried out in Kane-Kane, if the weight changes of the cows were individually monitored, their body condition scored and fecal production measured, dairy production was not measured individually and was also affected by the heterogeneity of the cows lot (age, breed, physiological status). Thus a function was established based on measured data to relate feed supplementation and milk production (table 113)

**Table 113**: Daily production of milk per cow and total benefit (CFA) per herd.

| Diet treatments | Daily milk production (l) | Annual benefit |
|---|---|---|
| cows not supplemented | 0.5 | 11538 |
| N supplemented cows. | 0.8 | 18460 |
| P supplemented cows | 1.45 | 33459 |
| N + P supplemented cows. | 1.75 | 40381 |

Two ways were used to calculate gross product of the cattle supplementation either based on the average weight gain (method 1), or based on the actual weight at onset and end of the trial with prices per unit weight which would reflect the body condition of the animal (table 114).

**Table 114**: Ex-post estimates (two mode of calculations) of total variable costs, net benefit and marginal rate of return of three supplementation options for cattle, Kane-Kane, 2000.

| Items (per cow) | Control | N-Supplemented | P- supplemented | N & P supplemented |
|---|---|---|---|---|
| Initial weight | 225 | 225 | 225 | 225 |
| Final weight | 181.3 | 225 | 259 | 268.7 |
| Mean weight gain (kg) | -43,7 | 0 | 34 | 43,7 |
| Mean sale price (/kg) | 375 | 405 | 575 | 600 |
| Mean purchase price (kg) | 350 | 350 | 350 | 350 |
| Product from weight gain | -16390 | 0 | 19550 | 26220 |
| Product from milk | 11540 | 18460 | 33460 | 40380 |
| Product from manure | 915 | 595 | 915 | 995 |
| Gross product (1) | -1335 | 19055 | 53925 | 67595 |
| Gross product (2) | -10875 | 12375 | 70175 | 82470 |
| Total variable costs | 2600 | 11625 | 43725 | 44420 |
| Due to nutrition tests | 0 | 692,25 | 32540 | 33235 |
| Due to labour | 2500 | 10835 | 10835 | 10835 |
| Due to tools | 100 | 100 | 350 | 350 |
| Net benefit | -3935 | 7430 | 10200 | 23175 |
| Marginal rate of return % (1) | - | 126 | 32 | 65 |
| Marginal rate of return % (2) | - | 158 | 91 | 123 |

Economic assessments were not performed for the on-station trial, but the apparent contradiction of the results of phosphate supplementation using rock phosphate needs to be understood. One of the possible explanation is link to the different source of rock phosphate: Taïba rock phosphate was used at Bambey while Thiès rock phosphate were used at Kane-Kane. The different composition of the two sources may explain the diarrhoea observed at Bambey and their consequences on the animal. The phosphorus supplementations also differed by method to give the phosphorus: either as a powder mixed with cotton cake (Bambey) or diluted in the drinking water. It appears that the last solution was more efficient as the animals did not manifest repulsion to drink the solution and yet had no diarrhoea. The third difference relates to the doses of phosphorus given to the animals that were higher and perhaps too high in the on-station trials. The last was the nature of the bulk feed, grazed crop residues at Kane-Kane and groundnut haulms at Bambey. The feed quality of the ground nut is such that it is not surprising that supplementing with two levels of cotton cakes and three of rock phosphate did not significantly improved animal performances nor the N content in the faeces already higher in the control treatment than in the N supplemented treatments of the on-farm trial. However for P, the high supplementation in rock phosphate translated in very high levels of phosphorus in the faeces.

Soil amendment with manure from cattle variously supplemented for millet-groundnut crop
The variable costs were assessed for the alternative amendments with different quality of manure applied on a two-years rotation millet-groundnut carried out in the village of Kane-Kane in 2000 and 2001 (table 115)

**Table 115**: Base of total variable cost estimates in the manuring of millet-ground nut rotation trials in Kane- Kane, 2000-2001.

| Expenses (CFA) | Coûts des traitements individuels par opération culturales | | | | |
|---|---|---|---|---|---|
| | Control no manure | Manure not supplemented cows | Manure N supplemented cows | Manure P supplemented cows | Manure N+P supplemented cows |
| Manure application | 0 | 10000 | 10000 | 10000 | 10000 |
| First weeding | 2000 | 2250 | 2250 | 2250 | 2500 |
| Second weeding | 2500 | 2500 | 2500 | 3000 | 3000 |
| Thinning | 1000 | 2000 | 2000 | 2500 | 2750 |
| Third weeding | 2000 | 2500 | 2500 | 3000 | 3000 |
| Harvest and | 5000 | 6000 | 6500 | 6500 | 6500 |
| Total labour costs | 12500 | 25250 | 25750 | 27250 | 27750 |
| Manure cost | 0 | 20000 | 20500 | 20500 | 24000 |
| Total variable costs | 12500 | 45250 | 46250 | 47750 | 51750 |

From a strict economic point of view if the price of manure is included, only application of manure from cows supplemented in urea and phosphate have a positive marginal rate of return, and this margin is very small, certainly below the opportunity costs (table 116). However, manure is not bought by the farmers, it is just a buy product of their livestock activities, and when the total variable cost only include labour and nutrients inputs as feed supplemented the rates of return of labour and input cost is much more positive. In addition the residual effect of the treatments on next season yields could further increase the rate of returns.

**Table 116**: Calculation of net benefit and marginal rate of returns for different options of improved manure application to millet-groundnut crop in Kane-Kane, 2000-2001.

| Items (per ha) | Control no manure | Manure not supplemented cows | Manure N supplemented cows | Manure P supplemented cows | Manure N+P supplemented cows |
|---|---|---|---|---|---|
| Mean yield (kg) | 599.45 | 743.76 | 817.28 | 835.66 | 1007.95 |
| Mean price (CFA $kg^{-1}$) | 100 | 100 | 100 | 100 | 100 |
| Gross product | 59945 | 74376 | 81728 | 83566 | 100795 |
| Total variable costs | 12500 | 45250 | 46250 | 47750 | 51750 |
| Net benefit | 47445 | 29126 | 35478 | 35816 | 49045 |
| Marginal rate of return % | Ref. | -56 | -35 | -33 | 4 |
| MRR with no manure cost % | Ref. | 148 | 158 | 155 | 212 |
| MRR relative to non supplemented cattel % | NA | Ref | 735 | 1574 | 628 |

### 2.6. Pathways for diffusion and adoption

Locally, the pathways for diffusion and adoption of the tested technologies include participatory evaluation of the technologies and results with farmers and technicians of the development agencies based in the village, especially PAGF, the IFAD funded project already intervening working on soil fertility management. Several visits were needed to define the mode of partnership. Farmers did provide their animals, the millet stover and bran, their land for the crop trial and most of the labour required to measure the quantity of feed offered to and refused by the animals, the harvest and urea treatment of millet stover, the collection and weighing of faeces produced, the weighing of the animals, blood sampling on a sub-sample of animals, the manure application and sowing, weeding and harvest of the millet crop.

Contacts and collaboration were also established with the agriculture, livestock and forestry extension agents, including the IFAD funded projects. Open days and farm visits have been regularly organised. Meetings were organised to report and discuss the results with all partners. Technical reports were written and technical pamphlets are planned. In 2002, a 'feed-back' workshop was organised in Kane-Kane to document farmers perception of the trials, to discuss the results with them in a meeting open to 160 participants including 100 farmers, villages chief from the district, the Regional Director of the Agriculture Department and other governmental agencies, as well as NGOs (Worldvision, Senagroconsult), and the PAGF-FIDA as a main partner. The workshop was well covered by the media with papers published in four national newspapers, and a film produced for the Senegalese TV. The project and demonstration trial seems to have triggered agriculture development initiative in the villages chosen in this project which have acquired some notoriety through their implication in the project.

At the regional level, contacts maintained with development agencies allowed exchange of information on tested technologies and their expected impacts not only on the farms and villages of the benchmark site, but also regionally. Scientific communications were given, as for Mme Cissé contribution to the AITVM conference at Copenhagen in August 2001.

## IV. Research main outputs, achievements and limitations.

Much progress has been achieved in evaluating the feasibility and potential economic impact of proposed nutrient management technologies. In all study countries, farmers have been classified into recommendation domains. The classifications showed how the nutrient management interventions proposed under this project fit into existing farm plans and resources available to each recommendation domain. This helped to identify the group of farmers that, *ceteris paribus*, can be expected to adopt and benefit from particular interventions. This classification together with the ex-ante economic analysis allowed lessons to be drawn from survey results to re-orient some of the on-farm technical trials (from sheep to cattle supplementation in Senegal; Abandon of the dairy production in some village located too far from markets in Mali).

GIS maps have been developed for 3 sites covering 500 $km^2$, 10 villages and 532 households in Niger. A consultant modeler has been recruited to lead this effort. Contacts have also been established with modelers from the University of Wageningen who developed the NUTMON nutrient flow model. Adaptation of this model to fit the peculiarities of crop-livestock systems in the study countries, particularly the communal use of a large fraction of forage resources, has been discussed. The modeling effort will provide decision support tools that can be used to explain the impact of alternative natural resource management options to farmers and policy makers in the case of low input mixed crop-livestock systems.

Progress has been made in identifying the household level factors that may facilitate or hinder the adoption of the proposed nutrient management technologies, and the differential impacts that the new technologies may have on men and women. These findings have been communicated to the agronomists and animal nutritionists participating in this project to enable them incorporate the most important factors into technology design. Because of the rapid turnover of economists associated with this project in all the participating countries, no progress has been made in the actual construction of a policy analysis matrix. This tool is needed to define the incentives and distortions created by government policy for agricultural production and, in particular the use of purchased inputs in the study countries. Possible solutions to overcome the problem posed by lack of progress on this activity were discussed at the last meeting of the steering committee of the project in July 2001 and it was decided that a workshop should be organized in February 2002 to move this activity forward. The workshop was held taking opportunity of the Steering committee meeting in February.

Although the results obtained under to improve soil fertility and crop/fodder production through the efficient use of farm residues, animal manure, local rock phosphate and purchased fertilizers, are not yet completed in that chemical analyses of soils and vegetation samples were not yet all available, yield results indicate that there is a large potential to increase crop and livestock production through more efficient nutrient cycling at plot, farm and landscape levels. Preliminary results also show that irrespective of the technology used to restore or improve soil fertility, it is important to capture the residual effects of interventions in order to include them in the biological and economic evaluations of the proposed technologies.

The originality of the trials conducted in livestock feeding lies in the fact they all tested the hypothesis that the effect of diet supplementation is not only reflected in increased animal productivity (measured in meat and milk output) but also on the quantity and quality of the excretions produced. However, the results obtained so far have proved insufficient to refute or accept this hypothesis either because the treatment effects were not significantly different, but more often because the numbers of animal per treatment and the heterogeneity of these animals did not permit conclusive statistical analysis. This is especially the case for on-farm trials. Furthermore, only partial results of chemical analysis of feed, extrusa and manure samples are available to allow full assessment of livestock performance or to assess the effect of the tested technology on nutrient cycling by livestock.

The main outputs of the project can be summarized for each of the five objectives of the project in the following list:

a) Assess ex-ante the potential impact and acceptability of technological alternatives on nutrient management.

- Farming systems were characterized at each benchmark site in a participatory way, and recommendation domains for crop-livestock technologies were identified.
- Farmer practices and perception of natural resource management (group interviews) were analyzed at each benchmark site.
- Marginal cost analyses were performed ex-ante systematically for most of the technologies tested at farm scale.

b) Improve the efficacy of livestock mediated nutrient transfers within village territories through better land use and institutional arrangements

- Social institutions controlling the access to nutrient inputs (fertilizers, insecticides, supplement feeds, veterinary drugs, cropping implements) surveyed and characterized at each benchmark sites.
- The impact of livestock on nutrient cycling at farm and community scales were assessed quantitatively and spatially in the villages of the Tillabery benchmark site (C, N, P and K flows and balances calculated per season and over the year for each farm type and globally for each farmer communities using the Nutmon software).

c) Promote adoption of nutrient management interventions through the identification of appropriate economic incentives and policy options

- Marginal cost analyses were performed ex-post systematically for most of the technologies tested at farm scale.
- Policy Matrix Analysis method were discussed and adopted for all benchmark sites through specific training workshop.

d) Improve soil fertility, and hence food crop and fodder production through strategic and efficient use of crop stalks, animal manure, local rock phosphates, chemical fertilizers and forage legumes.

- The use of compost made of excretions and feed refusal by tethered sheep and goats, enriched in P with rock phosphate was tested on millet-sorghum crop on-farm at Dori and Saria (Burkina Faso). Applied at 4 or 5 t $ha^{-1}$ once every two years it increased grain and stover production of sorghum, and also of associated cowpea in Namanéguéma, by 40 to 60%. The labour cost of compost making and transporting however reduced the profitability.

- The potential of a sweet sorghum cultivar (Malisor92-1) cropped on soil with 5t of manure and 150kg $ha^{-1}$ of rock phosphate to produce grains and high feed quality stalks was demonstrated on farm at Ségou (Mali).
- More efficient livestock corralling: lower rate of manure application per unit area, association with bedding mulch, simultaneous and relay application of low rates of placed inorganic fertilizer, was tested and demonstrated on-station in Sadoré and on-farm at Tillabery (Niger).
- Similar effect on millet yields at equivalent rates of P application for Dia-Ammonium Phosphate DAP (46% P2O5) and NKP 15-15-15 both placed applied at the hill was verified. It gives a net economic advantage to DAP, at least on the short term. Optimal economic returns were obtained for placed application of 0.8 to 1.0g P2O5 per hill, equivalent to 17 to 22kg $ha^{-1}$ DAP for a density of 10000 hills $ha^{-1}$ or to 53 to 67 kg $ha^{-1}$ NPK 15-15-15.
- More productive practices of millet-cowpea associated crop with adapted tillage, sowing density and geometry, insecticide (cowpea) and placed N-P-K or DAP applications were identified on station (Sadoré) and demonstrated on farm at Banizoumbou, Tillabery, Gaya and Maradi (Niger).
- More productive irrigated rice and burgu crops with the application of 6t $ha^{-1}$ compost made of cattle feces, rice straw refusals and house wastes enriched with rock phosphate were demonstrated on-farm at Kollo.
- More productive millet-groundnut rotation crop by application of cattle manure enriched in P through cattle supplementation with rock phosphate were tested on-station (Bambey) and demonstrated on farm at Kane-Kane(Diourbel, Senegal). The increase of feces contents in N, P, and K as the cattle were supplemented with either protein rich feed (groundnut haulms and cotton cakes in Bambey, groundnut cakes and urea in Kane-kane) or rock phosphate confirm previous results in Niger with urea and super-phosphates. However, it was a surprise that the groundnut, second crop in the rotation, did respond more to N and P treatments.

e) To increase meat and milk production and livestock contribution to efficient soil-plant nutrient cycling through better utilization of available feed resources.

- Cheap diets to fatten sheep with local fodder inputs were identified and tested on farm in Dori and Saria (Burkina Faso), Tahoua, Tillabery, Gaya and Maradi (Niger). Weight gains can easily be improved by 30% with no increase in the cost of feed. However, the economic profitability of sheep fattening depends largely on the market situation and on the trade ability of the farmer. For economy of scale, the profitability also increases with the number of sheep fattened, and thus with the capacity of the farmer to invest in the enterprise which is certainly higher for richer farmers. Moreover, the enterprise is limited by the capital that needed to be invested in buying the lean animals (the fattened animals originate the farmers herd only for the richer farmers) and some of the feed supplements.
- Cheap protein and minerals supplements for dairy goats were identified and tested on-farm at Dori (Burkina Faso). The supplementation of the dairy goat diet with cotton cakes and urea licks enhanced intake of bulk feed and thus enhanced milk production and attenuated weight losses of the dams. The cost of the protein supplement (100 to 200 g of cotton cakes) could be recovered rapidly by the sale of the milk generally controlled by the women.

- The use of sweet sorghum stalks to improve the feed value and reduce the cost of diet given to dairy cows was tested on-farm at Ségou and San (Mali).
- Cheap supplementation diets to fatten steers in peri-urban sites based on rice straws, wheat bran, brewery's wastes and urea licks (Kollo, Niger) or on Cotton cakes, molasses, millet bran and urea (Ségou, Mali) were demonstrated on farm. The profitability however is largely determined by assess and price of the crop residues and by-products.
- Cheap supplementation diets for peri-urban dairy cows fed rice straws including wheat bran, brewery's wastes and urea licks were demonstrated in peri-urban Niamey (Kollo). The profitability however depends largely on the access and price of agro-industrial by products.
- Effect of wet season and early dry season transhumance associated or not to end of dry season supplementation (millet bran, P) on cow weight gains and reproduction performance were measured on farm at Tillabery (Niger).
- The fact that cattle body condition was maintained or increased and weights largely increased by a protein, energy and mineral rich supplementation given late dry season was not a surprise. However, it was interesting to observe that phosphorus supplementation given alone, or together with the energy-rich supplement, increased significantly performances as demonstrated on farm at Kane-Kane. These results were not confirmed by the experiment carried out on station but the source of rock phosphate was different, as well as doses (much higher on station) and the way to give the phosphorus: either as a powder mixed with cotton cake (Bambey) or diluted in the drinking water which seems more easily tolerated by the animals. The difficulties to administrate phosphate in a solid form, even mixed with palatable supplements, already mentioned in an experiment carried out in Niger are confirmed.

Beyond these research results and the local impact that these research activities may have had in the farms and benchmark sites where activities took place, the project certainly contributed to change minds from partners in directions which will influence their future decision. In scientists and technicians directly involved in the project multidisciplinary, especially between biological sciences and human sciences, and participatory research approaches involving farmers, agents from development institution, traders in the research process from planning to review became evidence. The vision of crop and livestock interactions that many partners had was enriched given them a better sense of the potential that these interaction represent for agriculture intensification. The potential of farmers association to attract project activities, facilitate funding and access to credits was certainly witnessed locally by the farmers involved in the project activity who also increased their experience in ways to increase productivity and benefit.

## V. Recommendations to farmers and for policy options

Technological trials demonstrated the large potential to increase productivity of both crop and livestock while keeping or improving the status of soil fertility. The success and adoption of alternative technologies largely depends on the access to inputs and information. A prominent way for farmers to improve access to both inputs and information is to get organized, and reinforce capacities of existing farmers organizations. Access to credit for example is often conditioned by the strength of the farmer (could be women, youths, specialized cooperatives) associations.

- Thus, the first recommendation to farmers is to get organized in professional associations as most partners in agriculture development cannot deal with individual farmers. Many NGO's have the skills and experience and are ready to help.

Then, most of the technological recommendations are site and farm-type specific, however some broad lines can be drawn:

- When feasible (theft risks, labor), corralling livestock in the fields is the cheapest and the more efficient method to recycle animal excretions to cropland. Feces deposition in the field during the course of the year, and not only at the end of the dry season, contributes to reduce soil erosion by wind and run-off.
- However, when corralling is not applicable (risks of thefts, labor constraint, too few animals), compost making using the feces of the animals either stall fed or kept at night in the house yard, feed refusals and organic house wastes is profitable. Good quality compost requires however regular addition of water, which could be a constraint or very labor demanding, the cost of the digging the pit could eventually eliminated by opting for a 'stack compost' technique.
- Enrichment of compost in phosphorus by adding rock phosphate has proved efficient and profitable both on irrigated rice and rainfed sorghum. It is a easy way to apply rock phosphate which is difficult to apply efficiently in the fields due to its powder texture.
- As availabilities are limited and transportation labor demanding, compost amendments could be plant placed, just as inorganic fertilizer , especially on marginal soils were crops are sown in planting pits in order to benefit from run-on on the hardened soil surface (Zaï or Tassa system).
- Nutrient losses by leaching could be reduced by applying manure at rates lower than 6t DM $ha^{-1}$. When manure is applied by corralling, this implies more frequent moves of the livestock corral spots which has a labor cost largely covered by the benefits of the manure application when the effects are calculated over the four years of cropping that followed corralling.
- Nitrogen losses by ammonium volatilization from urine deposition could be reduced by adding a litter on the floor at the corralling spot or at the barn where animals are kept at night.
- For many farmers, the livestock managed do not produce enough manure to cover crop nutrient needs, small rate of P (4kg P $ha^{-1}$) and N inorganic fertilizer could be applied hill-placed to increase crop productivity. In Niger at present prices, DAP reveals cheaper at equivalent rate of P and effect on millet or sorghum crop. The association of hill-placed inorganic N and P fertilizer at small rate of application with corralling manure or compost is profitable at least in the short run.
- The need to increase fertilizer inputs, and for some crops pesticides, justify crop diversification toward cash crops, especially when these cash crops are legumes such as cowpea, groundnut, Bambara nut, Dolychos, which contribute to improve the soil fertility by fixing Nitrogen.
- Selected breeds of cereals such as sweet sorghum are valuable for the superior quality feed of their stalks to improve dry season diets of dairy animals.
- Saving could be realized by substitution of some external inputs by internally produced ones. This could apply to feed supplements given to dairy cow or goats, or to animals fattened for sale. However, the economic profitability of fattening and dairy depends largely on the market situation and on the trade ability of the farmer.

For fattening the profitability also increases with the number of animals fattened, and cooperation between farmers, farmers associations and access to credit could be determinant in the success of such enterprises.

- One advantage of dairy over fattening is the rapid recovery of the investment in supplement feeds as the dairy products are sold on the market. This allows progressive investments, more accessible to the poorest farmers providing they are endowed dairy cattle or goats (there are traditional entrustment of dairy animals in the Fulani culture such as ‘habanaï’ and ‘talfi’ that permit the poorest farmers to manage and benefit from lactating animals). The market of dairy products being generally controlled by women, the promotion of dairy production by strategic supplementation is also a way to promote women contribution to the household economy.
- Feed supplementation of grazing animals, especially with females in the late dry season is a common practice. Results in Senegal demonstrated that rock phosphate alone (75 g per cow and per day diluted in the drinking water) helped animal to keep body condition during that difficult period, and improve their weight gain. However, it is not advised to exceed that dose and to administrate the rock phosphate in solid form.

## VII. Unsolved problems and perspective for future research

Problems unsolved during the first phase are of different nature and could be grouped in three categories:

- In a first category the problems are relative to the overall goal of the project ‘contribute to poverty alleviation and improvement of food security in semi-arid West Africa.’ This overall goal was pursued through the overall objective to increase crop-livestock productivity through better nutrient management and decomposed into five specific objectives. Was this approach successful? What were the constraints encountered? What strategy should be followed to overcome these problems in a project second phase?
- In a second category the unsolved problems are of scientific nature. They often are defined within a discipline and linked to questions unsolved either because they were not properly addressed or because the results were contradictory to each other. These could be listed has scientific problems to clarify in a project second phase.
- In a third category the problems are methodological in essence and group constraints linked to the overall approach or to particular methodologies used in the first phase and that should be revised in a project second phase.

### Poverty alleviation and food security through better nutrient management

During the first phase the project was successful in establishing with the participation of the farmers a diagnostic of the constraints for agriculture development in a number of selected benchmark sites. However, the project impact was very much limited to the communities and individual farmers involved in the surveys and trials. Crop, livestock and soil management trials demonstrated the large potential to increase productivity of both crop and livestock while keeping or improving the status of soil fertility, but adoption and diffusion of these technologies were limited.

One of the possible reasons for the shortcomings was insufficient integration between the socio-economic surveys and the soil-crop-livestock technology trials. Although the project teams made considerable efforts to better harness technological trials and socio-economics (ex-ante and ex-post marginal rate of return on investments became a routine; some trials were adjusted to take care of socio-economic constraints…), a gap still exists between the outputs of the socio-economic survey and technological trials. On one hand the trials only deal with a few components of the production system, in spite of the effort made to systematically associate crop, livestock and soil management activities. On the other participatory surveys led to broad spectrum but quite generic characterizations and problem identifications. Farm-type characterization for example, resulted in a farm ranking in three to four wealth classes that were determined mainly by farm endowments in labor, croplands, livestock, farm implements…The technology tested either relate trivially to these endowment levels (farm potentially interested in planting sweet sorghum to feed dairy cattle only if they have dairy cattle and if there is a market for milk) or are not related (the use of rock phosphate put into drinking water to supplement cattle in the dry season does not relate to farm endowments except for the presence of cattle). An additional reason is that the tools used to assess the economical value of a technology were applied to a single commodity (crop or livestock) and not to the combined activities, nor to the whole farm system. For that reason only a some of the trade-off within farm were accounted for, and none of the implications on between farm exchanges. The complexity of the biological and economic trade-offs between crop-livestock commodities requires the development of adapted tools to assess the economic and environmental impact of one or several technologies. This tool should include simulation model and spatially explicit models of nutrient flows at farm and community land scale. Special effort should be made in a second phase to pursue the efforts to adapt existing simulation models to the communal use and management of natural resources such as water, grazing resources, most of woody plant products.

An other sets of reasons comes from the limited success of the collaboration between Nutman, as a research project, with the rural development project, in spite of all the efforts made and good will demonstrated. Since the project inception, IFAD pushed for effective collaboration, especially with IFAD funded development projects. All the projects intervening in the selected benchmark sites were approached, in some case, as in Senegal and Mali, benchmark sites were selected or changed to better match with the activities of existing development projects. Contacts were established, information exchanged, field agents collaborated. However only in a few cases, and to limited extend, was the collaboration successful in promoting the technology outside the boundaries of the benchmark sites. This shortcoming should be tackled in the second phase. One of the constraints to proved technology adoption or diffusion is farmer access to capital and credits on one hand and to information on the other. There is need to meet both requirements better focusing on the selected technologies as it was done with the ILRI/ICRISAT/FAO-Intrants/Aquadev/Moriben consortium in Niger with a package that included placed fertilizer, donkey drawn weeding implement, sheep fattening diets.

**Scientific issues in crop-livestock production systems in the Sahel.**

Progress were made in assessing the relative performances of the alternative mode of application of livestock excretion, crop residues and house wastes as soil amendments: either through livestock corralling, through manure harvesting in night paddocks and deposition on the field, or compost making and application to the field. However, the trade-off remains to be fully evaluated and the biological processes involved fully analyzed. For example the fate of nitrogen from both feces and urine excretions, the physical (mulch effect protecting from soil erosion), chemical (pH and nutrient) and biological effects of the depositions depending on the quality of the material deposited and the timing of the deposition should be studied. The three alternative mode of application should finally be assessed for the rate use efficiency by consecutive crops of main nutrients, N, P and K taking volatilization and leaching into consideration.

The processes of the interactions between litter and excretion deposition should be clarified in order to help identify the practices that would most efficiently recycle excretion Nitrogen to the benefit of crop growth. The potential of different organic material used as litter at the corralling spots or in the barns to fix some of the urine nitrogen should be quantified while the effect of urinary deposition on the kinetics of decomposition of the organic material should assessed.

The trade-offs of simultaneous or staggered application of organic amendments such as crop residues, house wastes, manure or compost with small amounts of inorganic fertilizers, especially N and P fertilizers remain to be fully assessed and recommendations for strategies and integrated soil fertility management drawn up for discussions and demonstration trials with farmers.

Contradictory results were observed on the effects of N and P nutrients brought as chemical fertilizers and/or manure enriched in nutrients on the grain and fodder production of legumes. Groundnut in Senegal and cowpea in some Niger trial did respond significantly to P and to N, while in other trials no response was observed.

On station and on-farm trials in western Niger converged to establish the superiority of cereal-legume rotation over their association. Yet, rotation is not adopted and the proportion of legume in the association practiced by the farmers systematically much lower than the experiment optimum. The justification of farmer's practice should be further investigated and solutions for increased efficiency of the association found together with farmers.

Many studies including some protocols developed during the first phase of Nutman project highlighted the importance of woody plant in the grazing livestock diets, especially at the end of the dry season, and their role in soil water use and nutrient cycling. Farmers have a large knowledge in agro-forestry, and practices such as selective clearing, field hedges and orchards management are part of tradition. However, adoption of wood lots or field hedge planting with multipurpose woody plants has little or spatially limited success. The tenure, labor and capital constraints are known and there is a need to solve them in a participative way.

On the livestock production side, further research is needed to assess how efficient is 'compensatory growth' to make up with the higher weight losses of poorly fed livestock during the late part of the dry season. What are the consequences of these losses on the reproduction performances and what are the physiological processes involved in compensatory growth. In order to properly assess the technical and economical benefit of feed supplementation packages given to reproductive females in the late dry season on the reproductive performance of the females.

Contradictory results of mineral supplementation with phosphorus given to cattle have been observed: high rates of supplementation with Taïba rock phosphates in Senegal have lead to diarrhea and aggravated weight losses, while no toxicity symptoms were observed with lower doses of Thiès rock phosphate mixed with drinking water which improved weight performance and the quality of the manure produced.  Same improving effects on manure quality was observed in Niger at very low doses of super-phosphate mixed with millet bran but phosphate was not easily accepted by the cows and affected intake. There is a need to better understand the criteria of acceptability, the risks of toxicity of phosphate supplementation in livestock diets.

**Methodological issues raised by applied research on crop-livestock systems in the Sahel.**

The project setting that associated multidisciplinary teams from four national agronomic research institutes with scientists from three international agronomic research institutes facilitate interdisciplinary and regional exchanges. However, it has not been an easy development. First discussions between partners were quite difficult and explain, at least in part, for the initial delay of the project inception. These initial difficulties also caused some of the soil-crop and livestock experiments to be initiated before the socio-economic survey had been conducted or analyzed which lead to later revisions of the research agendas. If considerable progress were made as the project developed in the multidisciplinary and participatory approaches, the bases for the collaboration between national and international scientists was questioned. If the international institute mainly intervened in setting methodologies and training in the case of socio-economy, they also carried out their own field and herd experiments at least in Niger where they were based. And it was filled that these activities were more competitive than complementary.

An other set of methodology issues were generated by the strongly supported on-farm experiments that consisted in either crop trials or animal nutrition trials.  When looking at the design and the mode of implementation, trials actually ranked between scientist controlled experiments in a farmer field (or on farmers animals) and trials fully controlled by the farmer under a design discussed between scientist and farmer.

- In experiments controlled by the scientist there is no restriction on the type of design, the number of replicates… however, the field conditions differ from research station, and the level of control required for some trial are not achievable at realistic cost. One example is given by the communal grazing system which applies allover the village lands, at least after crop harvest, during the dry season. It impedes control of stocking rate, and thus grazing pressure and excretion deposition on the land.
- In experiments controlled by farmers, the number of treatments has to be limited (2 to 4), replicates are only few if any. In the case of the dairy cattle nutrition trials in Mali for example, most farm had not enough cows in lactation to have even one animal per treatment, and those animals obviously differ in many ways: age, parity, breed. In the case of the trials in the village of Kane-Kane, the animals of different farmers had to be put together to run the trial. These constraints reduce largely the power of the data analysis. However, it depends on the objectives of the trial and the number, the 'demonstration trials' carried out by close to 150 farmers of 10 neighboring villages in western Niger had only three treatments in 2000 and four in 2001, including a control, with no replicates, each farm being considered a bloc also characterized by variables related to rainfall, type of soil and manure application history of the field that were used as co-variables.
- An additional difficulty of on-farm trial has been the definition of the control treatment. The farmer is not ready to have one (or several) animal or crop put at risk by the nature of a 'control treatment', with very low or no input. Yet this reference if

often required for the economic assessment of the other treatments and allows wider comparisons across site.

- Another understanding of the ‘control’ treatment was ‘farmer practice’. The difficulty however is that this practice may differ largely from one farmer to next, or even for one farmer, he may adapt his practice to the condition of each individual animal or to the fertility of each piece of land. The data analysis is then very much limited. Compromise solutions could sometimes be found like with the fattening sheep trial run in Niger in which the non-supplemented control was owned by the research institute and solely entrusted to the farmer who was paid the additional work.
- Another difficulty was found when the objective of the trial was to find a cheapest input treatment than in local practice. It was the case in Niger for the soil amendment of irrigated field, with compost and rock phosphate instead of imported inorganic fertilizers. It was also the case in Mali for fattening cattle, or supplementing dairy cattle with the objective of replacing par of the expensive agro-industrial by-product normally used by farmers by cheapest locally produced supplements. The calculation of the economic rate of returns on investments require that a ‘true’ control (with no or very low inputs) be added to the design.

Bio-economic modeling is required to assess holistically the environmental and economic impact of alternative technologies or policies that will farmers decisions. Such models have already been developed by other research teams, in other production systems and attempts were made to adapt them to Sahel mixed crop-livestock systems. There is however a major constraint to this adaptation due to the communal, if not public, management of grazing resources. The ‘farm’ model cannot be limited to the lands cropped (under various tenure) by the farm household, as their herds exploit the resources (water, grazed fodder) over a much larger area, and reciprocally many other herds than the household animals are exploiting the grazing resources on the farm land, on which the farmer has not control. There is a need to build a decision support system by pulling existing legume/fodder, phosphorus, nitrogen and livestock oriented database so as to identify/optimise/validate technological options for more efficient P and N use for sustainable crop-livestock integration. The decision support system should include GIS for evaluating spatial variability for farmer resource allocation, NUTMON for calculating/predicting nutrient flow, livestock model for efficient crop-livestock integration, and alternative simulation model including DSSAT 3.5, APSIM and QUEFST for predicting crop response to fertilizer nutrient and optimising fertilizer use efficiency in farming systems dominated by integrated soil fertility management.

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